

NCHRP

RESEARCH REPORT 880

NATIONAL
COOPERATIVE
HIGHWAY
RESEARCH
PROGRAM

Design Guide for Low-Speed Multimodal Roadways

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NCHRP RESEARCH REPORT 880

**Design Guide for Low-Speed
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2018

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research is the most effective way to solve many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation results in increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

Recognizing this need, the leadership of the American Association of State Highway and Transportation Officials (AASHTO) in 1962 initiated an objective national highway research program using modern scientific techniques—the National Cooperative Highway Research Program (NCHRP). NCHRP is supported on a continuing basis by funds from participating member states of AASHTO and receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board (TRB) of the National Academies of Sciences, Engineering, and Medicine was requested by AASHTO to administer the research program because of TRB's recognized objectivity and understanding of modern research practices. TRB is uniquely suited for this purpose for many reasons: TRB maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; TRB possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; TRB's relationship to the National Academies is an insurance of objectivity; and TRB maintains a full-time staff of specialists in highway transportation matters to bring the findings of research directly to those in a position to use them.

The program is developed on the basis of research needs identified by chief administrators and other staff of the highway and transportation departments, by committees of AASHTO, and by the Federal Highway Administration. Topics of the highest merit are selected by the AASHTO Special Committee on Research and Innovation (R&I), and each year R&I's recommendations are proposed to the AASHTO Board of Directors and the National Academies. Research projects to address these topics are defined by NCHRP, and qualified research agencies are selected from submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Academies and TRB.

The needs for highway research are many, and NCHRP can make significant contributions to solving highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement, rather than to substitute for or duplicate, other highway research programs.

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FOREWORD

By **Waseem Dekelbab**

Staff Officer

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NCHRP Research Report 880: Design Guide for Low-Speed Multimodal Roadways (1) provides best practice guidance to the designer by referencing a range of acceptable elements, criteria and values for critical dimensions for design of low- to intermediate-speed (45 mph and lower design speed) roadways with a mix of users and (2) assists designers in establishing a balance between operational efficiency, comfort, safety, and convenience for modes on the low- and intermediate-speed roadways. The report also includes detailed design case studies of design processes. The material in this report will be of immediate interest to design practitioners and stakeholders involved in the planning and design of streets and roadways that serve a mix of motorized and non-motorized users on facilities designed for low and intermediate speeds.

There is increasing recognition that successful roadway geometric design must provide an appropriate balance of service and safety for all users, including the consideration of cyclist and pedestrian users, and be coordinated with the uses and “context” of adjacent properties. The 2011 AASHTO *A Policy on Geometric Design of Highways and Streets* (the Green Book) recognizes this need, but provides limited specific guidance on how to incorporate this balance in the roadway design process. Little established practical engineering design guidance exists on how to effectively integrate and balance the service to all transportation modes along the same facility, corridor, or intersection. Most available geometric design guidance is based upon design for a single mode and does not fully address or incorporate the often competing needs of other modes requiring attention.

For example, because of the vulnerability of pedestrians and cyclists, they are involved in a disproportionate number of serious injury and fatal collisions at intersections. Factors that include a roadway functional classification, roadway operating speed, current and projected user demand, adjacent context, and community goals present a challenge in creating geometric designs that adequately recognize and provide for a mix of transportation modes and trip types, and reflect the priority that each should be given. This can be particularly difficult for certain intermediate-speed situations, which present a combination of multimodal features that may not integrate well or be congruent with each other. The design process should apply to roadways of all types, but particularly those in an environment of limited right-of-way, congested traffic conditions, and other routine multimodal design challenges. In addition, there was a need for a methodology for optimizing the balance of tradeoffs between geometric design elements and safety and operational performance for all users of these facilities.

Under NCHRP Project 15-48, Gresham, Smith and Partners was asked to develop a set of integrated guidelines that will help designers accommodate all users in the design of low- and intermediate-speed roadways, including:

- Methods to identify the mix of users that need to be served on various roadway functional classifications (context, area types, etc.) and speed categories (low and intermediate speeds);
- Methodologies supported by empirically based research and best practices that can balance and optimize how geometric design elements provide for safe and effective operation;
- Geometric design parameters for the types and designs of facilities to serve all users, and
- Examples showing how facilities representing various roadway functional classifications and speed categories have been or could be designed effectively.

In addition to the guidelines published as NCHRP Report 880, the research agency's final report that documents the entire research effort is available on the web page for NCHRP Project 15-48 at the TRB website (<http://apps.trb.org/cmsfeed/TRBNetProjectDisplay6.asp?ProjectID=3416>).



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Design Guide for Low-Speed Multimodal Roadways

Roadway designers strive to provide for the needs of highway users while maintaining the integrity of the surrounding context, community values, and environment. Unique combinations of design requirements, controls, and constraints that often conflict among different roadway users require unique design solutions. The guidance supplied by *NCHRP Research Report 880: Design Guide for Low-Speed Multimodal Roadways* (the Guide) is based on established best practices and is supplemented by recent research where possible.

The U.S.DOT encourages public agencies, professional associations, advocacy groups, and others to commit themselves to fully integrating bicycling and walking into their transportation policies and programs. The U.S.DOT also recommends that the design manuals commonly used by highway designers and that cover roadway geometrics, roadside safety, and bridges should incorporate design information that integrates safe and convenient facilities for bicyclists and pedestrians—including people with disabilities—into all new highway construction and reconstruction projects.

The intent of this Guide is to provide best practice guidance to the designer by referencing a range of acceptable elements, criteria and values for critical dimensions in the design of low- to intermediate-speed (45 mph and lower design speed) roadways with a mix of users. Good design involves balancing safety, mobility, and preservation of scenic, aesthetic, historic, cultural, and environmental resources. The Guide provides extensive information and guidance for multimodal design, but it is not intended to be a detailed design manual that eliminates the need for the application of sound principles by a knowledgeable design professional.

Sufficient flexibility exists in national design policy (such as AASHTO's *A Policy on Geometric Design of Highways and Streets*, called the Green Book) and its use is also encouraged throughout this Guide to create independent designs tailored to particular combinations of travel demands, context and community goals and values. When ranges of dimensional values are presented, additional information is often provided to assist the designer in deciding whether the upper, lower, or intermediate values are most appropriate for a particular situation. Engineering judgment is necessary in any design process to select the best combination of geometric controls, criteria and elements that best balances the safety, accessibility and mobility of all user travel modes.

The Green Book emphasizes the joint use of transportation corridors by pedestrians, bicyclists, and public transit vehicles. It also recommends that designers recognize the implications of this sharing of the transportation corridors and are encouraged to consider “not only vehicular movement, but also movement of people, distribution of goods, and provision of essential services.”

This Guide is intended to assist designers in establishing a balance between the operational efficiency, comfort, safety, and convenience for modes on the low- and intermediate-speed roadways. Context sensitivity and environmental quality are also key considerations in the design process and should result in aesthetic consistency with the surrounding terrain or urban setting as appropriate to create roadways that are safe and efficient for users, acceptable to non-users, and in harmony with the environment.



CHAPTER 1

Introduction

1.1 Purpose, Objectives and Organization of the Guide

1.1.1 Purpose

Before automobiles evolved in the 20th century, streets and roads primarily served a mix of slow-moving pedestrians, bicycles, horses and wagons in a manner that facilitated interaction with adjacent land uses. As motorized vehicles evolved and their ownership and usage grew, many roadways began to be designed to separate the motorized vehicle mobility function from the economic and social functions of adjacent businesses and neighborhoods. Roadway design priorities became increasingly focused on moving motorized vehicles as fast and efficiently as possible with decreasing attention to serving the lower numbers of non-motorized users using the right-of-way, even in urban contexts where the non-motorized users remained a significant presence.

For many of today's street and roadway facilities, especially those in urban and suburban contexts, accommodation of walking and bicycling requires retrofitting the motorized vehicle dominant transportation network to provide new or enhanced pedestrian and bicycle infrastructure. These facilities also often exist in constrained rights-of-way. This requires a greater awareness of the flexibility and versatility available in national guidance to help designers overcome many challenges related to retrofit and new alignment projects. Designers must also manage conflicts between all modes as an important element of the inclusion process. Pedestrians are the most vulnerable roadway user because they are at the greatest risk of injury or death in a collision with someone traveling by any other mode. Bicyclists generally travel at slower speeds than motorized vehicles and are inherently more vulnerable in the event of a crash with a car, truck, or transit vehicle. Designers need practical information and guidance based on real-world scenarios to address a variety of conflicts that can occur between different modes.

NCHRP Research Report 880: Design Guide for Low-Speed Multimodal Roadways (the Guide) has been developed in response to these real design challenges and a growing national interest in improving both the safety and mobility for non-motorized users in the right-of-way (i.e., pedestrians, bicyclists and transit riders). This growing focus is especially prevalent in the low- and intermediate-speed corridors of urban and suburban areas. Additionally, many cities, counties and state agencies are striving to improve the character of their roadways through a commitment to creating more integrated transportation networks that result in more walkable, bikeable and transit-friendly communities and regions. Design professionals can better achieve these goals by applying the concepts and principles in the Guide to ensure that all roadway users, the community and other key considerations are properly considered in the geometric design process.

This Guide provides designers, planners and policy makers with information on designing safer, more comfortable, and accessible roadway facilities so that walking and biking are safer and more convenient transportation choices for all users. It identifies and addresses common concerns and perceived barriers among design professionals concerned about liability when designing pedestrian and bicycle facilities, and directs them to the most current national guidance that provides specific information on multimodal design treatments and approaches.

U.S.DOT policy encourages agencies and designers to consider and address the needs of pedestrians and bicyclists in the provision of all transportation facilities. U.S.DOT guidance to improve pedestrian and bicycle accommodation is provided in *Accommodating Bicycle and Pedestrian Travel: A Recommended Approach*, which can be found at the Federal Highway Administration's (FHWA) *Bicycle and Pedestrian Program* website (https://www.fhwa.dot.gov/environment/bicycle_pedestrian/guidance/design.cfm). The "Policy Statement" section of the website includes the following sections:

1. Bicycle and pedestrian ways shall be established in new construction and reconstruction projects in all urbanized areas unless one or more of three conditions are met:
 - Bicyclists and pedestrians are prohibited by law from using the roadway. In this instance, a greater effort may be necessary to accommodate bicyclists and pedestrians elsewhere within the right-of-way or within the same transportation corridor.
 - The cost of establishing bikeways or walkways would be excessively disproportionate to the need or probable use. Excessively disproportionate is defined as exceeding twenty percent of the cost of the larger transportation project.
 - Where sparsity of population or other factors indicate an absence of need. For example, the Portland Pedestrian Guide requires "all construction of new public streets" to include sidewalk improvements on both sides, unless the street is a cul-de-sac with four or fewer dwellings or the street has severe topographic or natural resource constraints.
2. In rural areas, paved shoulders should typically be included in all new construction and reconstruction projects on roadways used by more than 1,000 vehicles per day. Paved shoulders have safety and operational advantages for all road users in addition to providing a place for bicyclists and pedestrians to operate. Rumble strips are not recommended where shoulders are used by bicyclists unless there is a minimum clear path of four feet in which a bicycle may safely operate.
3. Sidewalks, shared use paths, street crossings (including over- and under-crossings), pedestrian signals, signs, street furniture, transit stops and facilities, and all connecting pathways shall be designed, constructed, operated and maintained so that all pedestrians, including people with disabilities, can travel safely and independently.
4. The design and development of the transportation infrastructure shall improve conditions for bicycling and walking through the following additional steps:
 - Planning projects for the long-term. Transportation facilities are long-term investments that remain in place for many years. The design and construction of new facilities that meet the criteria in item (1) above should anticipate likely future demand for bicycling and walking facilities and not preclude the provision of future improvements. For example, a bridge that is likely to remain in place for 50 years might be built with sufficient width for safe bicycle and pedestrian use in anticipation that facilities will be available at either end of the bridge even if that is not currently the case.
 - Addressing the need for bicyclists and pedestrians to cross corridors as well as travel along them. Even where bicyclists and pedestrians may not commonly use a particular travel corridor that is being improved or constructed, they will likely need to be able to cross that corridor safely and conveniently. Therefore, the design of intersections and interchanges shall accommodate bicyclists and pedestrians in a manner that is safe, accessible and convenient.
 - Getting exceptions approved at a senior level. Exceptions for the non-inclusion of bikeways and walkways shall be approved by a senior manager and be documented with supporting data that indicates the basis for the decision.
 - Designing facilities to the best currently available standards and guidelines. The design of facilities for bicyclists and pedestrians should follow design guidelines and standards that are commonly used, such as the AASHTO *Guide for the Development of Bicycle Facilities* [AASHTO 2014b], AASHTO's *A Policy on Geometric Design of Highways and Streets* [AASHTO 2011a], and the ITE's *Design and Safety of Pedestrian Facilities* [ITE 1998].

The Guide will help designers and planners better understand and facilitate the often complex multiple functions of modern urban and suburban streets. It provides guidance for the design of multimodal streets and roadways where all motorized and non-motorized modes must co-exist in places where community goals are aimed to provide a more balanced approach to accommodating the safety and mobility of all user modes. The Guide summarizes the flexibility and versatility available in existing national design guidance. It also addresses how a designer can reduce liability concerns through proper application of engineering judgment, design process documentation, and experimentation when justified. The Guide builds on that foundation by introducing guiding principles for reducing conflicts between modes.

1.1.2 Objectives and Organization

The objectives of this Guide are to:

1. Identify techniques and approaches for how street and roadway design processes should accommodate and integrate all users on urban and suburban facilities and within the built-up areas of small villages and towns;
2. Describe the relationship, compatibility and trade-offs in selecting design controls, criteria and elements that may be appropriate when balancing the needs of all users, adjoining land uses, environment and community interests when making decisions in the project design process;
3. Describe the principles of context-sensitive solutions (CSS) and the benefits and importance of these principles in designing transportation projects for all users; and
4. Present guidance on how to identify and select appropriate design parameters and criteria to best meet the needs of all legal users that exist in a particular context setting.

The Guide addresses three specific realms of multimodal design: design of the traveled way, design of roadsides and design of intersections. These topics and supporting information are addressed in six chapters:

- Chapter 1 provides an overview of the document that includes its purpose, objectives and structure;
- Chapter 2 outlines and discusses the design considerations for all user groups and their inter-relationships in low- and intermediate-speed contexts;
- Chapter 3 addresses the process of assessing and balancing service levels among all user modes in low- and intermediate-speed contexts;
- Chapter 4 provides specific criteria and guidance for designing all aspects of the traveled way of integrated multimodal streets, roads and intersections across a range of types, speeds and land use contexts;
- Chapter 5 provides specific criteria and guidance for designing all aspects of the roadside of integrated multimodal streets and roads across a range of types, speeds and land use contexts; and
- Chapter 6 provides design examples that illustrate the process of considering and selecting design elements, controls and criteria in different context settings.

1.2 Intended Users

This Guide is intended for design practitioners and stakeholders involved in the planning and design of streets and roadways that serve a mix of motorized and non-motorized users on facilities designed for low- and intermediate-speed ranges of 45 miles per hour (mph) and below. Users of the document are encouraged to consider the principles and guidelines presented in conjunction with applicable local policies and manuals.

Although design practitioners will likely be the predominant user of the document, it is expected that other professional disciplines engaged in the street and roadway design process, including transportation planners, traffic engineers, land use and community planners, urban designers and landscape architects, may also find the Guide useful. Each of these groups will often represent a different set of perspectives and responsibilities to the project development process that best addresses the needs of their stakeholders to be served by the final design solutions.

1.3 Range of Facilities Addressed

Designing streets and roads that effectively and safely serve all legal users of the right-of-way is a crucial responsibility of all designers and transportation agencies with roadway design responsibilities. The level of service (LOS) and quality of service (QOS) to any mode can vary greatly depending on a range of factors that include the relative volumes of each mode, the facility's desired functional classification within the street network, existing and desired vehicle operating speeds, right-of-way dimensions and geometry, and the context of the project area. Although the concepts and principles of CSS can be applied to all types of transportation facilities in all contexts, the Guide focuses on applying the concepts and principles to the planning and design of low- and intermediate-speed streets and roadways that typically exist in urban and suburban areas, as well as low-speed rural areas such as the built-up areas of rural villages and towns. *NCHRP Research Report 855: An Expanded Functional Classification System for Highways and Streets* reflects the context zone approach developed in NCHRP Project 15-52 to assist designers in applying geometric design flexibility (Stamatiadis et al. 2017). Four of the five context zones developed in that project are used as a foundational element of this Guide.

Within these contexts, the guidelines focus on facilities where a mix of motorized and non-motorized users is most likely and where designing for them is most challenging. Typically, these facilities will include the conventional functional classifications of primary and minor arterials, major and minor collectors, and local roadways in urban, suburban and rural villages/towns. These facilities, especially arterial and collector facilities, often serve significant volumes of higher-speed motorized traffic that must co-exist with increased levels of non-motorized users and transit service. Although freeways, expressways and major high-speed (50 mph and higher) arterials certainly exist in urban and suburban areas, design of these facilities is not addressed in this Guide. The table in Exhibit 1-1 summarizes the combination of roadway facility types, speed ranges and land use contexts addressed in the Guide. Given their typical low level of multimodal activity, roadways in rural undeveloped contexts are not the focus of these guidelines, but many of the design elements and approaches presented herein may be appropriate when non-motorized travel exists on those facility types.

Exhibit 1-1. Roadway facility types addressed in this Guide.

Functional Classification	Design Speed	Area Type and Predominant Context				
		Rural		Urban		
		Undeveloped	Village, Town, Built-up Areas	Urban Core	General Urban	Suburban
Principal and Minor Arterial	≤ 45 mph		X	X	X	X
	≥ 50 mph					
Major and Minor Collector	≤ 45 mph		X	X	X	X
	≥ 50 mph					
Local	≤ 45 mph		X	X	X	X
	≥ 50 mph					

1.4 Project Development and Design Process to Address All Users

The development process for roadway improvement projects in urban, suburban and low-speed rural areas may begin in the programming, planning or environmental processes of a transportation program. The ultimate ability of a project designer to provide a design that adequately considers and serves all legal users of a facility can depend on the decisions made during those early phases. It is important to ensure that necessary right-of-way, funding and contextual relationships are understood and considered. Too often, improvement projects have been conceived only on the future projection of motorized vehicle needs. This approach lacks an understanding and consideration of the current and future needs of the other users of the facility, the future context of the project area, and the community and neighborhood goals for the project.

The long-range transportation planning process provides an opportunity to identify those facilities and places where local agency land use and development policies benefit from and support context-sensitive roadway design (e.g., pedestrian-scale districts, town or village center designs, bicycle-priority facilities and transit corridors). The broader policy decisions can influence the development of appropriate roadway classifications and their design elements and dimensions. Multidisciplinary team and stakeholder involvement also are critical in the early phases of the design process. The fundamentals of urban and suburban context-sensitive design are addressed in Chapter 2, the modal priority-balancing process is the focus of Chapter 3 and the recommended design guidance framework is addressed in Chapters 4 and 5.

The project design concept should emerge from an understanding of the relationships between roadway classification and context types, along with other unique project circumstances, values or objectives. Additionally, a roadway's modal emphasis should ideally be identified in the early project concept development phases. The Guide provides tools for aligning various roadway types and speed conditions to various modal demands and contexts. It describes how to prioritize design elements and assemble the cross sections and intersection design features based on context and potentially constrained conditions. Data input to the project concept phase of project development should include information relating to the current and future use of all modal users, land use development patterns and design features that support present conditions. Equally important is the design team's vision for the project's future context.

An important step in project planning phase involves development and analysis of design alternatives, including an environmental review. Alternatives may be developed using the techniques and design criteria presented in the Guide, including accessibility. Each alternative should incorporate appropriate design characteristics that are compatible with the context of the facility and community.

The preliminary engineering and final design phases should be driven by carefully selected design controls and detailed guidelines. The Guide provides information to establish an initial design for testing, identify trade-offs and prepare a final concept for engineering.

It bears repeating that applying the information presented in the Guide requires an understanding of both the *existing* context and the *future* context of the project area. The application of context-sensitive principles also requires the designer to know how to use the design of the roadway/facility to support existing and planned adjacent land uses and development patterns.

1.5 Applicability

The information in this Guide can be applied to designing low- and intermediate-speed roadways of all functional classifications that safely and effectively serve legal users of all ages and abilities, both present and planned, in urban and suburban contexts and built-up areas of villages and towns.

Most applications of the guidance provided herein will occur in the context of (1) a roadway project in an existing community where the roadway's multimodal character is to be preserved and enhanced, or (2) a roadway project in an area where community goals call for a multimodal context. In the latter case, applying this design guidance will shape public investment to advance those goals. Both circumstances can apply to either new construction or retrofit projects.

Projects in all community and development contexts will benefit from applying the guidance presented in this Guide. In areas such as central business districts, suburban business parks, residential subdivisions and strip commercial development, the Guide can help designers provide benefits that include:

- Safe, comfortable, accessible facilities for pedestrians and bicyclists;
- Safe and convenient access to transit;
- Aesthetically pleasing roadside and median areas;
- Appropriate sizing of facilities with respect to pavement width, with associated potential for cost savings in right-of-way acquisition, construction and maintenance;
- Successful integration of transit facilities and operations; and
- Management of vehicle speed appropriate to the context.

1.6 Relationship to Other Design Guidance

The Guide supplements and expands on policies, guides and standards commonly used by state and local transportation, engineering and public works engineers and planners. Frequently referenced publications include:

- *A Policy on Geometric Design of Highways and Streets* (AASHTO 2011a);
- *Guide for the Planning, Design and Operation of Pedestrian Facilities* (AASHTO 2004b);
- *Guide for the Development of Bicycle Facilities* (AASHTO 2014b);
- *Highway Safety Manual* (AASHTO 2010); and
- *Roadside Design Guide* (AASHTO 2011b).

This Guide also refers to state and federal department of transportation design policies and manuals, local municipal street design standards, urban design guides and guidance published by other organizations such as the Institute of Transportation Engineers (ITE) and National Association of City Transportation Officials (NACTO).

The Guide expands on information published by FHWA and AASHTO in *Flexibility in Highway Design* (FHWA 1997), *A Guide for Achieving Flexibility in Highway Design* (AASHTO 2004a), and in the *Manual on Uniform Traffic Control Devices*, or MUTCD (FHWA 2009b). Another FHWA publication, *Achieving Multimodal Networks: Applying Design Flexibility and Reducing Conflicts* (FHWA 2016a), continues to build upon the considerations in developing roadway designs that are context sensitive and result in safe and effective multimodal designs. The Guide helps illustrate how current AASHTO guidance can be applied to roadway improvement projects to make them more accommodating for all users, community objectives and surrounding context on low- and moderate-speed facilities in urban and suburban areas.

The flexibility encouraged by the Guide is consistent with the policies and intent expressed in the Green Book (AASHTO 2011a). Most of the criteria in the Guide are based on current AASHTO design criteria, and this report shows how the criteria can be applied to create roadway geometric designs that effectively serve all users in low- and moderate-speed contexts. The Guide also presents information from sources other than AASHTO. All sources cited are collected in the References section following the chapters. By reference, this report also incorporates consistency with guidelines and standards published in the latest versions of the *Americans with*

Disabilities Act Accessibility Guidelines (ADAAG) (U.S. Access Board 2002) and the *Proposed Guidelines for Pedestrian Facilities in the Public Right-of-Way* (PROWAG) (U.S. Access Board 2011). The latter two documents are available online at www.access-board.gov.

Augmenting information found in the above resources, the Guide also addresses:

- Providing safe and convenient accommodation of all legal modes in project design;
- Applying context-sensitive principles in the design of low- and intermediate-speed roadways;
- Considering a broader set of factors during the design of multimodal roadways;
- Recognizing the importance of context, the role of sites and buildings and how context influences the design of the roadway and vice versa; and
- Providing an understanding of how roadway design criteria can, and should, vary depending on the context through which the roadway passes.

Some devices and applications discussed in the Guide are covered under Interim Approvals in the MUTCD (FHWA 2009b). Examples include green-colored pavement in bicycle lanes and rectangular rapid-flash beacons. FHWA approval must be obtained before these devices can be installed.

Sources of Additional Information

FHWA. 2011. *Livability in Transportation Guidebook: Planning Approaches that Promote Livability*. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. Online: https://www.fhwa.dot.gov/livability/case_studies/guidebook/livabilitygb10.pdf.

FHWA. 2015f. *Separated Bike Lane Planning and Design Guide*. Publication Number: FHWA-HEP-15-025. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. Online: https://www.fhwa.dot.gov/environment/bicycle_pedestrian/publications/separated_bikelane_pdg/page00.cfm.

NACTO. 2016. *Transit Street Design Guide*. National Association of City Transportation Officials, New York. Online: <https://nacto.org/publication/transit-street-design-guide/>.

TRB. 2010. *Highway Capacity Manual* (HCM). Transportation Research Board of the National Academies, Washington, D.C.

TRB. 2016b. *Highway Capacity Manual, 6th Ed.: A Guide for Multimodal Mobility Analysis* (HCM). Transportation Research Board of the National Academies, Washington, D.C.



CHAPTER 2

Design Considerations for All Users in Low- and Intermediate-Speed Environments

This chapter addresses a wide range of design considerations for low- and intermediate-speed (45 mph or less) roadways and streets that serve a mix of user modes, particularly the vulnerable-user modes of pedestrians and bicyclists.

2.1 Design Controls, Criteria and Elements

Controls are physical and operational characteristics that guide the selection of criteria in the design of thoroughfares. Some design controls are fixed, such as terrain, climate and certain driver-performance characteristics, but most controls can be influenced in some way through design and are determined by the designer.

The Green Book (AASHTO 2011a) and *A Guide for Achieving Flexibility in Highway Design* (AASHTO 2004a) identify location as a design control and establish different design criteria for rural and urban settings. AASHTO recognizes the influence context has on driver characteristics and performance. The Green Book defines the environment as “the totality of humankind’s surroundings: social, physical, natural and synthetic” and states that full consideration to environmental factors should be used in the selection of design controls. The Guide focuses on design controls and critical design elements for all users in low- and intermediate-speed roadway environments, particularly urban and suburban contexts where a wide range of users can be expected.

The Green Book identifies functional classification and design speed as primary factors in determining highway design controls and criteria. The Green Book generally separates controls and criteria by both roadway functional classification and two levels of context: rural and urban. The primary differences between rural and urban contexts are

- The typical speed ranges at which the facilities operate,
- The mix and characteristics of the users, and
- The opportunities and constraints of the surrounding context.

In addition to functional classification, speed and context, AASHTO presents other design controls and criteria that form the basis of its recommended design guidance. The basic controls are:

- Design vehicle;
- Vehicle performance (acceleration and deceleration);
- Driver performance (e.g., age, reaction time, driving task, guidance);
- Traffic characteristics (volume and composition);
- Capacity and vehicular LOS;
- Access control and management;

- Pedestrians and bicyclists;
- Safety;
- Environment; and
- Economic analysis.

The Green Book also addresses the alignment and cross section of roadways and notes its impact on users, communities and the environment. A roadway's alignment is defined as a variety of design elements that combine to create a facility that serves users safely and efficiently, consistent with the intended function of the facility. AASHTO recommends that each alignment element should complement others to achieve a consistent, safe, and efficient design and lists several principal elements of design that are common to all classes of highways and streets. These elements include sight distance, horizontal and vertical alignments, superelevation, traveled way widening, grades, and all other cross-section elements addressed in the geometric design process.

The Green Book presents the pedestrian needs as a factor in highway design and recognizes the pedestrian as the “lifeblood of our urban areas.” Pedestrian characteristics that serve as design controls include walking speed, walkway capacity and the needs of persons with disabilities. The Green Book also states that the bicycle is an important element to consider in the design process and that while it notes that much of the roadway system itself allows for bicycle use, a number of special accommodations may be needed for specially designated bikeway facilities within the right-of-way (AASHTO 2011a). The *Guide for the Planning, Design and Operation of Pedestrian Facilities* (Pedestrian Facilities Guide), and the *Guide for the Development of Bicycle Facilities* (Bicycle Guide) expand significantly on the limited design policy and guidance content in the Green Book, presenting detailed factors, criteria and design controls (AASHTO 2004b, AASHTO 2014b).

This Guide emphasizes pedestrians and bicyclists as a design control in all contexts, but focuses on facilities operating in the low- and intermediate-speed ranges that exist primarily in urban, suburban and rural town/village contexts.

2.2 Conventional Versus Evolving Roadway Design Practice

The Guide presents design guidance that is generally consistent with the AASHTO Green Book, AASHTO's supplemental publications and conventional engineering practice. There are, however, four design controls in the application of non-motorized user, context-sensitive design principles that are used somewhat differently than in the conventional highway design process. These controls are:

- Functional classification;
- Design Speed;
- Design vehicle; and
- Land Use Context.

2.2.1 Functional Classification

In the geometric design process, it is important to identify and understand a roadway's role in the local, regional and statewide functional classification network. The Green Book recognizes, however, that relying entirely on functional classification to design a roadway can result in roadway facilities that do not consider the local context, and that design has impacts beyond just traffic service (AASHTO 2011a):

A highway has wide-ranging effects in addition to providing traffic service to users. It is essential that the highway be considered as an element of the total environment. The term ‘environment,’ as used here refers to the totality of humankind's surroundings: social, physical, natural, and synthetic.

In addition, FHWA's *Highway Functional Classification: Concepts, Criteria and Procedures* recognizes the challenges in balancing the goals of a facility's functional classification with the land use context and mix of users that may be present (FHWA 2013b):

After a functional classification has been assigned to a roadway, however, there is still a degree of flexibility in the major controlling factor of design speed. There are no 'cookie-cutter' designs for roadways. Instead, there is a range of geometric design options available.

Although the functional classification of a facility may remain constant along a route, it is suggested that the design of the facility change as needed to recognize the context, mix of users and community goals of the areas through which the roadway travels.

2.2.2 Design Speed

The most influential design control, and the design control that provides significant flexibility in urban areas, is speed. Roadway design in areas with existing or planned multimodal activity normally are designed with the intent of achieving a "target speed" for the facility that best balances safety, accessibility and mobility for all users.

Design speed is used as the primary design control in the AASHTO Green Book. Conventionally, design speed has been encouraged to be as high as is practical. This Guide alters the focus from design speed to *target speed*, which is driven by the functional classification, roadway type and context, including variations in the type of land use context within the project limits.

FHWA's guidance memorandum on the relationship between design speed and posted speed states that "[in] urban areas, the design of the street should generally be such that it limits the maximum speed at which drivers can operate comfortably, as needed to balance the needs of all users" (FHWA 2015c). The design guidance in the Guide has been developed based on the concept of determining and designing to a selected target speed not only in urban contexts, but in any low- and intermediate-speed facility context where multimodal users are present or expected to be present in the future.

Target speed typically is defined as the highest operating speed at which vehicles should ideally operate on a roadway in a specific context. The target speed should complement the level of multimodal activity generated by adjacent land uses to provide both mobility for motorized vehicles and a safe environment for pedestrians and bicyclists. The target speed is intended to become the posted speed limit. In some jurisdictions, the speed limit must be established based on measured speeds. In these cases, it is important that the design consider the context of the roadway, encouraging a desired operating speed that helps ensure actual operating speeds will match the speed limit. Target speed then becomes the primary control for determining the values of the following geometric design elements:

- Minimum intersection sight distance;
- Minimum sight distance on horizontal and vertical curves; and
- Horizontal and vertical curvature.

Target speeds typically range from 25 mph to 35 mph for roadway types that are considered *walkable* and *bikeable* by today's practices. These lower target speeds are a crucial characteristic of roadways in mixed-use areas, traditional urban areas, some suburban areas, developing rural areas, and small towns and villages on rural roadways. On urban and suburban roadways with higher volumes of vehicular traffic and planned operating speeds ranging from 40 mph to 45 mph, providing a safe and accessible design to accommodate non-motorized users is even more important. In these cases of higher volumes and speeds, additional treatments and safeguards for non-motorized users usually are warranted.

2.2.3 Design Factors that Influence Target Operating Speed

Establishing a target speed that is artificially low relative to the design of the roadway will only result in operating speeds that are higher than desirable and difficult to enforce. Consistent with AASHTO policy, the Guide urges sound judgment in the selection of an appropriate target operating speed based on a number of factors and reasonable driver expectations. Factors in urban areas include transitions between higher- and lower-speed roadways, terrain, intersection spacing, frequency of access to adjacent land, type of roadway median, presence of curb parking and level of pedestrian and/or bicycle activity. AASHTO's guide to flexibility in highway design aptly summarizes the selection of a target operating speed in urban areas (AASHTO 2004a):

Context-sensitive solutions for the urban environment often involve creating a safe roadway environment in which the driver is encouraged by the roadway's features and the surrounding area to operate at lower speeds.

Roadway design for a facility that is intended to accommodate walking and bicycling should start with the selection of a target speed. The target speed should be applied to those geometric design elements where speed is critical to safety, such as horizontal and vertical curvature and intersection sight distance. The target speed is not set arbitrarily; rather, it is achieved through a combination of design and operating measures that normally includes many of the following design elements:

- Using narrower travel lanes that encourage motorists to naturally slow their speeds;
- Using physical measures such as curb extensions and medians to narrow the traveled way;
- Using design elements such as on-street parking to create side friction;
- Providing minimal or no horizontal offset between the inside travel lane and median curbs;
- Eliminating superelevation;
- Eliminating shoulders in urban and suburban applications, except for bicycle lanes;
- Incorporating smaller curb-return radii at intersections and eliminating or reconfiguring high-speed channelized right turns;
- Introducing roundabouts or traffic circles to produce slow points;
- Paving materials with texture (e.g., crosswalks, intersection operating areas) detectable by drivers as a notification of the possible presence of pedestrians;
- Setting signal timing for moderate progressive speeds from intersection to intersection; and
- Ensuring proper use of speed limit, warning and advisory signs, as well as other appropriate devices to gradually transition speeds when approaching and traveling through areas with multimodal activity.

Other factors widely believed among roadway design practitioners to influence speed include a canopy of street trees, the psychological enclosure of a roadway formed by the proximity of a wall of multistory buildings, the striping of edge lines or bicycle lanes and the presence or absence of parking lanes. These features are all elements of urban and some suburban contexts, but they should not be relied upon as speed reduction measures until further research provides more definitive guidance regarding their impacts to all users.

The design practitioner is advised to be careful not to relate speed to capacity in urban and suburban areas at low and intermediate speeds, and to avoid the assumption that a high-capacity street requires a higher target speed. Under interrupted-flow conditions, such as on roadways in urban/suburban areas, intersection operations and delay normally have a greater influence on capacity than does speed.

2.2.4 Design Vehicles

The vehicle chosen for geometric design greatly influences the selection of design criteria such as lane width and curb-return radii. Some agencies and practitioners will conservatively

require the design to accommodate the largest design vehicle that could use a roadway (e.g., WB 50 to WB 67), regardless of the frequency. Consistent with AASHTO guidance, context-sensitive design and consideration of all users emphasizes an analytical approach in the selection of a design vehicle, including evaluation of the trade-offs involved in selecting one design vehicle over another.

In urban areas, it is not always practical or desirable to choose the largest possible design vehicle, particularly if such a vehicle will use the facility only occasionally. The impacts of this design choice—on pedestrian crossing distances, speed of turning vehicles and other aspects of the roadway—may be inconsistent with the community’s vision, goals and objectives for the roadway. At the same time, selection of a smaller design vehicle in the design of a facility that is regularly used by large vehicles can invite frequent operational problems. To balance these two concerns, practitioners are encouraged to select two types of vehicles for use in the design process: (1) a design vehicle representative of the vehicles that will use the facility frequently (e.g., a bus on bus routes, a semi-tractor trailer on primary freight routes or routes accessing loading docks) and (2) a control vehicle representative of the type of vehicle that will use the facility infrequently.

The design vehicle must be regularly accommodated without encroachment into the opposing traffic lanes. The control vehicle’s infrequent use of a facility must be accommodated, but encroachment into the opposing traffic lanes, multiple-point turns, or minor encroachment into the street side is deemed acceptable. A condition that uses the design vehicle concept arises when large vehicles regularly turn at an intersection with high volumes of opposing traffic (such as a bus route). A condition that uses the control vehicle concept arises when occasional large vehicles turn at an intersection with low opposing traffic volumes (e.g., a moving van in a residential neighborhood or once-per-week delivery at a business) or when large vehicles rarely turn at an intersection with moderate to high opposing traffic volumes (e.g., emergency vehicles). The inside apron of a roundabout also serves the same function allowing the occasional longer wheelbase vehicle to negotiate the design.

The practitioner generally can obtain classification counts to determine the mix of traffic and frequency of large vehicles in order to estimate how this mix will change as context changes, keeping the design consistent with the community’s long-range vision. If there are no specific expectations, the practitioner may consider the use of a single-unit truck or local transit vehicle as an appropriate design vehicle.

State highways have traditionally served through traffic and heavy/large vehicle traffic, but modern roadway system planning tries to accommodate movements using network and context considerations. Large, heavy and unusually demanding vehicles need to be accommodated with reasonable convenience; however, in some cases, routes other than state highways may be more appropriate or more easily accommodating to these vehicles.

2.2.5 Land Use Context

Conventional roadway design is controlled by location to the extent that it is rural or urban (and sometimes suburban) as defined in the AASHTO Green Book. The Guide broadens the choices for context using an expanded context range as outlined in Stamatiadis et al (2017). This recent research provides the following context areas:

- Rural;
- Rural village/town;
- Suburban;
- Urban; and
- Urban core.

This Guide also expands the variation in design elements controlled by location to include predominant ground floor land uses such as residential, commercial, school, park and so forth. Land uses (existing and planned/future) will generally govern the level of multimodal activity, which in turn influences the design of the roadway. These influences include, but are not limited to, pedestrians and bicyclists, transit, economic activity of adjacent uses and right-of-way constraints. The context-sensitive approach also considers planned land uses that represent changes in existing development patterns and special design districts that seek to protect scenic, environmental, historic, cultural, or other resources.

2.3 Roadway User Definitions and Characteristics

The Guide addresses three general categories of users of the roadway right-of-way. In addition, within each user category, generally accepted “classes” are important to consider in the design process. The categories of users are:

- Motorized vehicles;
- Pedestrians; and
- Bicyclists.

Because of their vulnerability in any crash situation with a motorized vehicle, pedestrians and bicyclists often are called “non-motorized” or “vulnerable” road users. These terms are used interchangeably throughout the Guide.

AASHTO’s Green Book guidance recognizes that addressing the needs of all users within the right-of-way is a necessary part of the geometric design process. The foreword to the Green Book includes the following statement (AASHTO 2011a):

Emphasis is placed on the joint use of transportation corridors by pedestrians, cyclists and public transit vehicles. Designers should recognize the implications of this sharing of the transportation corridors and are encouraged to consider not only vehicular movement, but also movement of people, distribution of goods, and provision of essential services. A more comprehensive transportation program is thereby emphasized.

2.3.1 Motorized Vehicles

The Green Book establishes four general classes of motorized design vehicles: (1) passenger cars, (2) buses, (3) trucks and (4) recreational vehicles. The passenger-car class includes passenger cars of all sizes, sport/utility vehicles, minivans, vans, and pick-up trucks. Buses include intercity (motor coach), city transit, school, and articulated buses. The truck class includes single-unit trucks, truck tractor-semitrailer combinations, and truck tractors with semitrailers in combination with full trailers. Recreational vehicles include motor homes, cars with camper trailers, cars with boat trailers, motor homes with boat trailers, and motor homes pulling cars. The Green Book also notes that if bicycle use is allowed on a roadway, the bicycle should also be considered as a design vehicle (AASHTO 2011a). Motorcycles are not mentioned specifically as a design class, but depending on their volumes, special design considerations may be warranted.

2.3.2 Pedestrians

A roadway that is designed to accommodate pedestrians must consider not only their volumes and travel needs, but also the wide range of needs and physical capabilities possible among different pedestrian groups. An agile, able-bodied person can frequently overcome accessibility challenges and pedestrian facility design deficiencies. When age or functional disabilities reduce

a person's mobility, judgment, sight, or hearing, however, providing proper design solutions becomes much more important.

The pedestrian user category includes four generally accepted and distinct classes:

- Able-bodied pedestrians with average or better agility;
- Pedestrians with mobility, vision or hearing disabilities;
- Older pedestrians with limited functions and/or mobility; and
- Younger pedestrians with more erratic behavior and generally smaller stature.

The interactions of all pedestrian classes with other users are a major consideration in roadway design. Pedestrians typically are a part of every roadway environment other than access-controlled roadways, and the Green Book recommends that their presence and needs be considered in both rural and urban areas. The higher volumes of pedestrians in urban, suburban and town/village areas means that they influence roadway design features more frequently than do the lower volumes of pedestrians in purely rural settings; however, the accommodation, safety and convenience of every type of user must be understood and fully considered in the design process.

Given the levels of vehicular traffic in urban areas, it is often difficult to balance the needs of pedestrians with the needs of vehicles (and sometimes bicycles). Pedestrians and motorized vehicles can often safely co-exist in low-speed, low-volume local roadway environments, such as residential neighborhoods. Pedestrian facilities typically are much more critical on roadways with higher speeds and volumes. Necessary accommodations can include sidewalks and their intersection/driveway interactions, crosswalks, traffic control features, and curb cuts (depressed curbs and ramped sidewalks) and ramps for older walkers and persons with mobility impairments. Pedestrian facilities also include transit stops or other loading areas, sidewalks on grade separations and the stairs, escalators or elevators related to these facilities. The PROWAG must be considered when designing pedestrian facilities in the roadway right-of-way (U.S. Access Board 2011).

2.3.3 Bicycles

The bicycle is an important element for consideration in the highway design process. In many urban and suburban areas, the existing street and highway system provides much of the network needed for bicycle travel. Motorized vehicles and bicycles often can safely co-exist in low-speed, low-volume roadway environments such as residential local street networks. As roadway speeds and volumes increase, accommodations for bicycles become a much more critical element of the design process.

The bicycle category includes three or four classes of user depending on the source consulted. For the purposes of the Guide, three classes will be used:

- “A” class: Advanced bicyclists with considerable experience and confidence;
- “B” class: Bicyclists of average skills and confidence; and
- “C” class: All other bicyclists (primarily children).

The interactions of all bicycle user classes with other users are another major consideration in roadway design.

Bicyclists are an increasing element in every roadway environment, especially in urban and suburban areas. The Green Book recommends that bicyclists' presence and needs be considered in both rural and urban areas (AASHTO 2011a). Balancing a roadway design to meet the needs of bicyclists, pedestrians and motorized vehicles can be a challenging process, especially in constrained roadways in urban and suburban areas.

Bicycle facilities take many forms, including signed routes, shared lanes with motorized vehicles, on-street striped bike lanes, on-street buffered bike lanes, separated bike lanes and bike paths/trails that are separated from motorized vehicle lanes or from the roadway altogether. Other bicycle facilities in the right-of-way may include intersection and non-intersection crossing locations, special traffic control signals, special roadway markings and bicycle parking accommodations.

2.4 Functional System Considerations

2.4.1 Roadway, Bicycle, Pedestrian and Transit Networks

Ideally, roadway design is based on a combination of local needs and the role of the facility in the area or region's transportation network. The functional classifications of roadways in a typical transportation network consist of principal and minor arterials, major and minor collectors and local roads and streets.

Planning for a roadway network should anticipate the needs generated by planned land uses (including intensity) while maintaining and promoting compatibility with the resulting neighborhoods and community. Community and neighborhood areas may have widely varying characteristics, needs, features and activity levels. The community's goals for the specific neighborhoods, areas, or corridors supported by the roadway network also may vary.

The roadway network typically develops over time in accordance with state and/or regional transportation plans (depending on the agency maintaining the facility) in coordination with a local community's comprehensive plan (or transportation plan). The density (spacing) of the network, the capacity (vehicle lanes, walkway, bicycle, transit), the space for landscaping, amenities and other components of the right-of-way should encourage and support the development pattern, land use type and level of development intensity in accordance with applicable plans. For many low-volume, low-speed local roadways, the various modes often can be accommodated in one travel space without providing separate facilities for each mode. As speeds, volumes and functional classification levels increase, the need increases to separate modal facilities to address safety and reduce potential conflicts.

The transportation network in any urban or suburban region should function as a system of corridors containing rights-of-way for vehicular, pedestrian, bicycle and transit networks that together meet and support the communities' desired urban or suburban form and growth. The level of roadway capacity provided for each mode will depend on the current and future projected local demand, the degree of interaction between the facilities and local land uses, the amount of multimodal activity generated and the amount of through travel using the roadway network. The design of any individual roadway needs to be responsive to the varied development and activities associated with changes in context zones throughout the project.

2.4.2 Network Planning Principles for Multimodal Roadways

Principles outlined in ITE's *Designing Walkable Urban Thoroughfares: A Context Sensitive Approach* outline an approach for planning and designing roadway networks that are sensitive to community objectives and context (ITE 2010a). Considering all of these elements in the design process will help create a balanced, multimodal environment for each roadway facility in the network. Chapter 3 of the ITE publication lists the following principles for creating effective, connected multimodal networks in urban and suburban areas for all types of users (ITE 2010a):

- Multimodal network planning should be integrated into long-range comprehensive plans that simultaneously address land use, transportation and urban form.

- Network planning should address multimodal mobility and access needs along with goods movement, utilities placement and emergency services.
- Reserving right-of-way for the ultimate width of roadways should be based on long-term needs of all users defined by objectives for both community character and mobility.

Ideally, network and corridor operating plans will serve all modes and all users, with uses varying on some roadways according to context, needs, objectives and priorities while considering overall network needs. Network rights-of-way that form a grid-like pattern of continuous roadways can better distribute traffic loading, and roadways can be interconnected with specified distances between intersections to:

- Provide choices of routes;
- Reduce travel distances;
- Promote use of transit, bicycles and walking;
- Accommodate utility needs; and
- Provide traffic control systems that support and encourage use of existing and planned walking, bicycling and transit modes.

2.5 Functional Classification and Urban Roadway Terminology

The roadway design process in the Guide refers to both functional classification and the urban “thoroughfare” type typically used to classify streets in urban areas.

Conventional federal functional classification is intended to define a roadway’s function and role in the network and govern the selection of certain design controls. Designers typically use the functional class to determine:

- Continuity of the roadway through a region and the types of places it connects (such as major activity centers);
- Purpose and lengths of vehicle trips accommodated by the roadway;
- Range of typical design speeds;
- Level of land access and level of access management;
- Type of freight service; and
- Types of public transit services (e.g., bus, bus rapid transit, light rail).

In urban and suburban areas, additional factors are typically considered to inform the designer’s decisions about both the physical design and the operations of the roadway, considering all users. These factors include:

- Categories, types and volumes of non-motorized users, both current and anticipated;
- The surrounding context, which is used to guide the most appropriate physical configuration (e.g., elements, criteria, dimensions) of the:
 - Traveled way (e.g., lanes, medians, on-street parking, on-street bicycle lanes);
 - Side of street (e.g., sidewalks, off-street bike facilities, landscaping, public space, user amenities);
 - Intersections; and
- A target speed appropriate for the context and mix of users; and
- Sight distance.

Exhibit 2-1 shows specific thoroughfare types that are commonly used in urban area planning in the United States and gives a general description of each type of facility. As this Guide focuses on roadways with design speeds at or below 45 mph, only four of the six types fall into this

Exhibit 2-1. Urban area thoroughfare type descriptions.

Thoroughfare Type	Functional Definition
Freeway/ Expressway/ Parkway	High-speed (50 mph +), controlled-access thoroughfare with grade-separated interchanges and no pedestrian access. Includes tollways, expressways and parkways that are high- or medium-speed (45 mph +), limited-access thoroughfares with some at-grade intersections. Parkways generally include landscaping on each side and a landscaped median. Truck access may be limited on parkways.
Rural Highway	High-speed (50 mph +) thoroughfare designed both to carry traffic and to provide access to abutting property in rural areas. Intersections are generally at grade.
Boulevard	Low- to intermediate-speed (30 mph to 45 mph), divided and undivided arterial thoroughfare in an urban environment and designed to carry both through and local traffic, pedestrians and bicyclists. May be a long corridor; typically four lanes but sometimes wider, serves longer trips and provides pedestrian access to land. May be a high-ridership transit corridor. Boulevards are primary goods movement and emergency response routes and use vehicular and pedestrian access management techniques. Boulevards may have raised medians or two-way left-turn lanes (TWLTLs), and curb parking may be used on some boulevards in low-speed settings.
Multiway Boulevard	Low- to intermediate-speed (30 mph to 45 mph) boulevard in an urban environment characterized by a central roadway for through traffic and parallel access lanes accessing abutting property, parking and pedestrian and bicycle facilities. Parallel access lanes typically are separated from the through lanes by curbed islands with landscaping; these islands may provide transit stops and pedestrian facilities.
Avenue	Low- to medium-speed (25 mph to 35 mph) urban arterial or collector thoroughfare, generally shorter in length than a boulevard and primarily serving access to abutting land. Serves as a primary pedestrian and bicycle route and may serve local transit routes. Avenues generally do not exceed four lanes, and access to land is a primary function. Goods movement is typically limited to local routes and deliveries. Some avenues feature a raised landscaped median. Avenues may serve commercial or mixed-use sectors and usually provide curb parking.
Street	Low-speed (25 mph to 30 mph) thoroughfare in an urban area that primarily serves abutting property. Streets are designed to (1) connect residential neighborhoods with each other, (2) connect neighborhoods with commercial and other districts and (3) connect local streets to arterials. A street also may serve as the “main street” of commercial or mixed-use sectors and emphasize curb parking. Goods movement is restricted to local deliveries only.
Rural Road	Low- to medium-speed (25 mph to 35 mph) thoroughfare in a low-density suburban area that primarily serves abutting property.

Source: Adapted from ITE (2010a)

category: boulevards, avenues, streets and rural roads. These roadway thoroughfare types typically serve a mix of modes, including pedestrians, bicyclists, motorized vehicles (for passenger and freight) and possibly transit.

Exhibit 2-1 does not address a fairly typical urban or suburban roadway type that has four to six through lanes, intermediate operating speeds (40 mph to 45 mph), and either no median, a two-way left-turn lane (TWLTL), or possibly a raised or flush pavement median. Inherent modal conflicts exist on these motorized vehicle-focused roadways that present significant design challenges to accommodating all modes.

Exhibit 2-2 shows the typical relationship between thoroughfare types used in community planning and roadway functional classification. In general, boulevards serve an arterial function, avenues may serve arterial or collector functions and streets typically serve a collector or local function in the network.

Exhibit 2-2. Relationship between functional classification and thoroughfare type.

Federal Functional Classification	Thoroughfare Types					
	Freeway/ Expressway/ Parkway	Rural Highway	Boulevard	Avenue	Street	Rural Road
Principal Arterial						
Minor Arterial						
Major/Minor Collector						
Local						

2.6 Modes: Separation, Integration and Conflict Reduction

When multiple user modes (e.g., pedestrians, bicyclists, transit, and motorized vehicles) operate in the same right-of-way, conflicts can and do occur. Producing designs that reduce conflicts is critical for vulnerable road users such as pedestrians and bicyclists. Vulnerable road users are at a higher risk of injury or death when involved in a crash with a motorized vehicle. Similarly, pedestrians and bicyclists alike are at a higher risk of injury or fatality when a crash occurs between them. The design guidance in this Guide provides practitioners with tools to better understand and reduce the potential for conflicts between modes using various processes, policies and design strategies.

Some design and operations treatments can eliminate most conflict potential between modes (e.g., grade-separated bike/pedestrian overpasses, all-red pedestrian phases at signalized intersections), but most roadways require designs that manage conflicts rather than eliminate them. Reducing conflicts between modes often involves evaluating performance trade-offs across modes with the goal of achieving the best balance of safety and other performance measures among all users.

FHWA's *Achieving Multimodal Networks: Applying Design Flexibility and Reducing Conflicts* provides the following guiding principles to minimize and manage conflicts where user modes cross or meet in the right-of-way

1. Safety

Do the design, operations, and maintenance decrease the severity and likelihood of crashes?

Where modes come together, the design should eliminate conflicts to the greatest extent possible.

If it is not feasible to eliminate the conflict, designers should minimize the speed differential between modes to ensure that if a crash occurs, the severity of the injury is likely to be lower. Safety considerations are also incorporated and implied in all other principles.

2. Accommodation and comfort

Does the design serve all modes and provide a sense of comfort?

Designs should accommodate people of all ages and abilities. Solving conflicts by eliminating access for pedestrians, bicyclists or transit users is not an acceptable solution.

3. Coherence and predictability

Are the facilities for each mode recognizable and consistent?

Where different modes come together, the design should provide clear right-of-way assignments, visibility of all users, and a clear path of travel for all modes, whether they are intended to operate in shared or separated spaces. This encourages predictable and safer behaviors for all users.

4. Context sensitivity

Does the design incorporate and support the natural environment and adjacent land use, such as transit stations, employment centers, and other destinations. Does it support community health, economic, and livability goals?

The management of conflict points should consider and incorporate access to current and future adjacent land uses. Designs should minimize barriers to walking, bicycling, and transit use, and promote improved economic, social and public health.

5. Experimentation

Are there innovative and creative solutions that can be tested to reduce conflicts?

Experimenting with new treatments to resolve multimodal conflict points should be considered to expand the tools available to improve multimodal accommodations and reduce the likelihood and severity of conflicts (FHWA 2016a).

In addition, ITE's *Recommended Design Guidelines to Accommodate Pedestrians and Bicycles in Interchanges* provides design guidelines for reducing conflicts and improving safety and accessibility for pedestrians and bicyclists within and across roadway interchanges (ITE 2016). The guidelines identify specific dimensions, safety features, signing, pavement markings, design geometries, and other treatments to address pedestrian and bicycle conflicts. The best practices in the report are intended to provide insight into future updates of statewide or federal highway design manuals.

2.7 Understanding and Assessing Context

The context of a roadway is a critical factor to consider in developing a project's purpose and need, making fundamental design decisions such as cross-section determination, and selecting detailed design elements such as roadside amenities, street light fixtures or construction materials. Development of a roadway design that is sensitive to and respectful of the surrounding context is ultimately important for project success.

Context-sensitive design refers to both the process and its results. An open stakeholder and community process that begins early in project development is desirable to ensure development of consensus about a project's purpose and need. This process should continue through the design phase so that the features of the project are assembled to produce an overall solution that satisfies the project's purpose and need, respects surrounding resources, and is consistent with the community goals and values.

Historically, the roadway design process has focused on a project's transportation elements, particularly those associated with motorized vehicle travel. A context-sensitive design should begin with analysis of the contextual elements, such as the environmental and community resources of the area through which a roadway passes. Beginning with a contextual analysis is critical in urban and suburban contexts as well as rural towns and villages. Once the designer understands the area surrounding the road and the road's users, the designer can then consider the transportation elements of the roadway, its function within the local and regional transportation system, and the appropriate level of accessibility of all users between the roadway and adjacent properties.

2.7.1 Context Definition

The context of a roadway begins with its environmental context, which includes nearby natural resources, terrain, and the manmade environment (development patterns, historic, cultural, and recreational assets). The environmental context can be a determinant of the desired type of accommodation for different users. This context often establishes the physical constraints of the roadway alignment and cross section, and it influences the selection of motorized vehicle design speed.

A roadway corridor frequently traverses a variety of changing environments. Additionally, the volume and character of pedestrian, bicycle, public transit, freight and motorized vehicle activity can change considerably along its route. Land use is the fundamental determinant in the

function of a road; as land use changes along a road, the road’s functions also change. Roadways should be designed to serve the existing land use while supporting the corridor and the community’s future land use goals.

2.7.2 Context Types

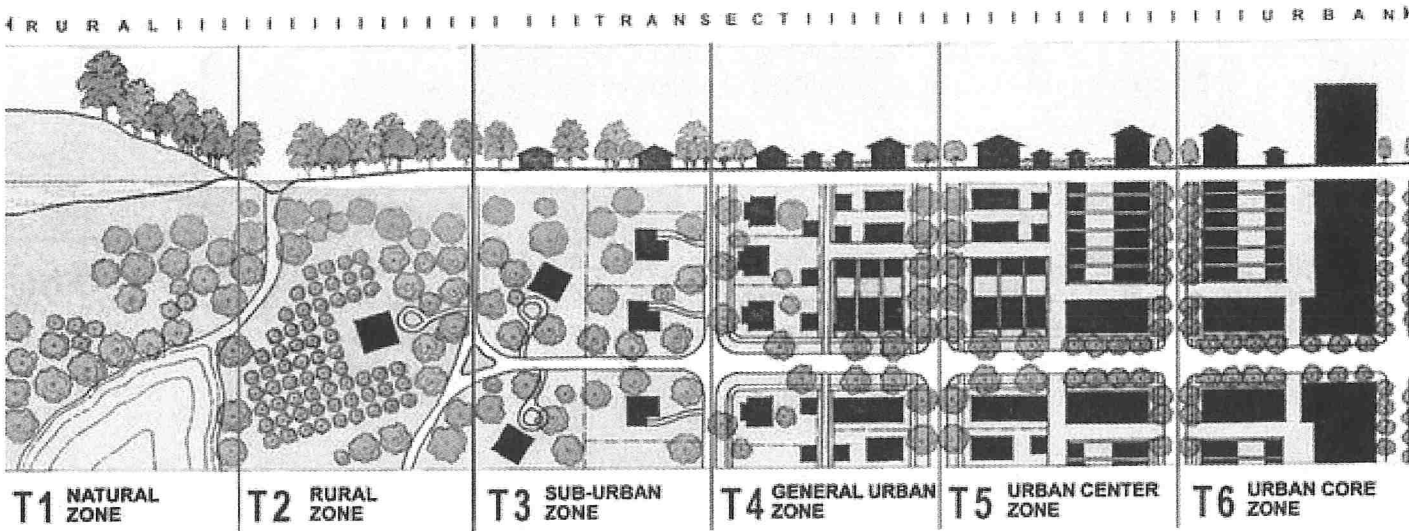
It is important to recognize that a roadway’s formal classification as urban or rural—which is determined from census data using criteria adopted (and periodically adjusted) by the United States Office of Management and Budget—may differ from actual site circumstances or prevailing conditions. For example, a rural arterial route passing through a small town may be classified as rural, but where the road passes through the town there may be a significant length over which the surrounding land use, prevailing speeds and transportation functions are more urban or suburban than rural. For this reason, it is important for the designer, working with the community and project stakeholders, to determine a project’s appropriate *context type*—or types—early in the planning process.

Context types illustrate the broad range of environments that the designer may encounter throughout a corridor. The designer should also identify unique or project-specific contextual elements that will influence the design beyond those generalized area types. These elements might include, but are not limited to, schools, churches, pedestrian or bicycle-focused areas, parks and recreation areas, economic/retail areas and transit service hubs.

2.7.3 Transect

Many urban planners use a concept called the “*transect*” to generally define land use context across a range of possible conditions from rural to urban areas. As shown in Exhibit 2-3, the transect is generally divided into six zones: core (T6), center (T5), general urban (T4), suburban (T3), rural (T2) and natural (T1). A remaining zone or category, special district, can be applied to unique parts of the urban environment that have specialty uses that do not fit into neighborhoods. Special districts could include power plants, airports, college campuses, and large retail-center power centers.

Exhibit 2-3. The transect—an organizing system for land use.



Source: DPZ SmartCode

Exhibit 2-4. Land use context zones in pre-publication draft of *NCHRP Research Report 855* (Stamatiadis et al. 2017).

Context Category	Density	Land Use	Setback
Rural	Lowest (few houses or other structures)	Agricultural natural resource preservation and outdoor recreation uses with some isolated residential and commercial	Usually large setbacks
Rural Town	Low to medium (single family houses and other single purpose structures)	Primarily commercial uses along a main street (some adjacent single family residential)	On-street parking and sidewalks with predominately small setbacks
Suburban	Low to medium (single and multifamily structures and multistory commercial)	Mixed residential neighborhood and commercial clusters (includes town centers, commercial corridors, big box commercial and light industrial)	Varied setbacks with some sidewalks and mostly off-street parking
Urban	High (multistory, low rise structures with designated off-street parking)	Mixed residential and commercial uses, with some institutional and industrial and prominent destinations	Minimum on-street parking and sidewalks with closely mixed setbacks
Urban Core	Highest (multistory and high rise structures)	Mixed commercial, residential and institutional uses within and among predominately high rise structures	Small setbacks with sidewalks and pedestrian plazas

Stamatiadis et al. (2017) considered the transect in developing land use context categories that expand on AASHTO's definitions of rural and urban areas. Exhibit 2-4 presents the latest evolution of those expanded context definitions and their typical land use type, density and expected building setbacks from the right-of-way. Essentially, the guidance from Stamatiadis et al. suggests two rural categories, one suburban category and two urban categories as described in the table.

Because this Guide focuses on multimodal activity within roadways operating in low- and intermediate-speed ranges (45 mph and lower), design guidance is provided for the rural town, suburban, urban and urban core categories. Rural streets and highways will often include areas with design and operating speeds above 45 mph as well as much lower levels of non-motorized user activity, but these contexts are not specifically addressed in the Guide. If a low-speed rural roadway facility is being designed to serve a mix of motorized and non-motorized users, however, the Guide will also be beneficial to the designer of that facility.

2.8 Context-Sensitive Design Principles

Context is an important consideration in designing roadways to accommodate all users because context generally drives the presence, levels and activities of non-motorized users. The principles of context-sensitive design promote a collaborative, multidisciplinary process that involves all stakeholders in planning and designing transportation facilities that:

- Meet the needs of users and stakeholders;
- Are compatible with their setting and preserve scenic, aesthetic, historic and environmental resources;
- Respect design objectives for safety, efficiency, multimodal mobility, capacity and maintenance; and
- Integrate community objectives and values relating to compatibility, livability, sense of place, urban design, cost and environmental impacts.

Applying the principles of context-sensitive design enhances the geometric design process by addressing objectives and considerations not only for the transportation facility but also for the surrounding area and its land uses, developments, economic and other activities and environmental conditions. With a thorough understanding of the context-sensitive principles and design process, the practitioner designing a roadway can integrate community objectives, accommodate all users and make decisions based on an understanding of the trade-offs that frequently accompany multiple or conflicting needs. The Guide provides guidance in how context-sensitive principles may be considered and applied in the process of developing street and roadway improvement designs for multimodal use.

As documented in the *Context-Sensitive Solutions Primer* (FHWA 2009a), TRB E-Circular E-C067 (TRB 2004), *NCHRP Report 480: A Guide to Best Practices for Achieving Context Sensitive Solutions* (Neuman et al. 2002) and other sources, the principles of context-sensitive design are successfully used in towns and cities as well as in rural areas. Integrating context-sensitive principles into the project design process results in the consideration of a broad range of objectives and an attempt to balance these objectives based on the needs and conditions specific to each project, all users and the project's context.

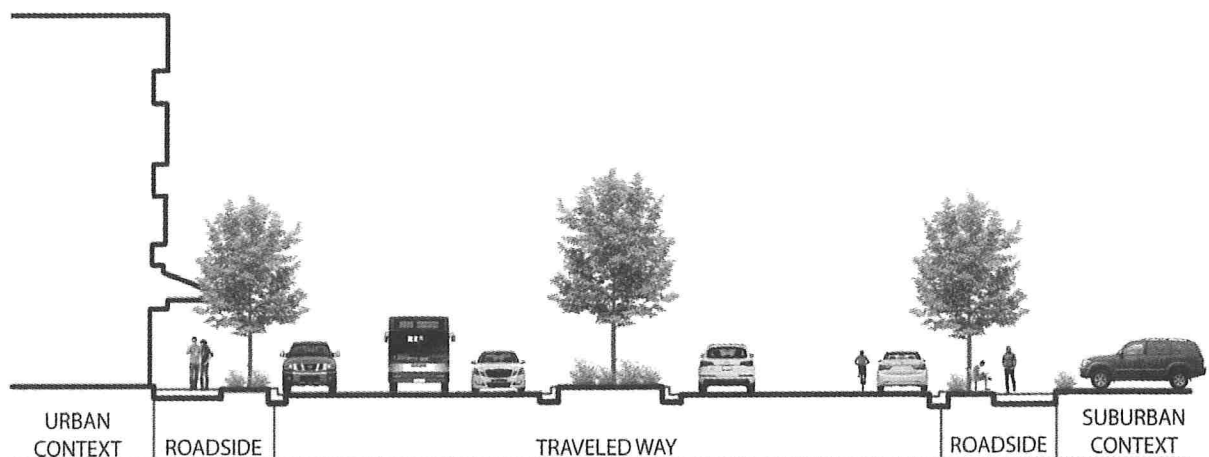
2.9 Relationship of Design Elements to Context

Designing streets and roadways for all users requires paying attention to many elements of the public right-of-way, including how these elements integrate with each other and with adjoining properties. Along a roadway, three basic elements must be designed to work together to provide a facility that effectively serves all users: (1) the traveled way, (2) the roadside and (3) the “context” (as defined by the adjacent property). These elements are illustrated in Exhibit 2-5. A fourth design element, intersections, is a unique component of traveled way design given the conflict potential within and across all user modes in the shared space of the intersection's functional area.

2.9.1 Context as a Design Element

Context encompasses a broad spectrum of environmental, social, economic and historical aspects of a community and its people. All of these aspects are important in applying context-sensitive principles to street and road design.

Exhibit 2-5. Design elements of a typical urban street.

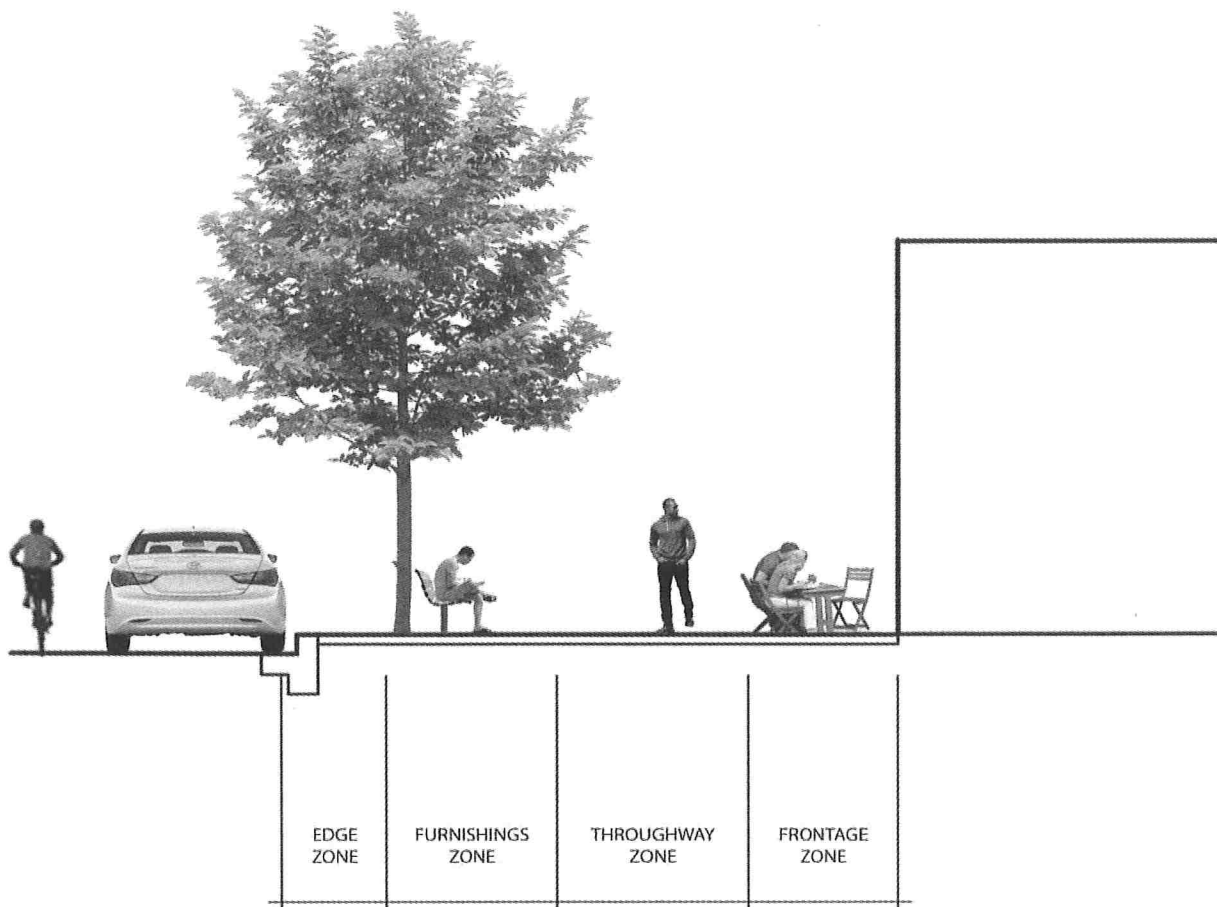


Broadly speaking, context can consist of an urbanized built environment, part of the natural environment, or both. The built environment consists of properties and activities within and adjacent to the public right-of-way—and the roadway itself—with surroundings whose characteristics help to define the context within that zone. Buildings, parking facilities, landscaping, land use mix, site access and public spaces are the primary elements of the built context. The natural environment generally includes undeveloped lands that may include open space or farming activities. In both environments, context can reflect historic or other protected resources. A roadway design will often change as its context changes from one zone to another. The roadway itself and the activity it supports become part of the context after it is completed.

2.9.2. The Roadside as a Design Element

In urban, suburban and rural town context zones, the public right-of-way typically includes planting areas and pedestrian facilities (sidewalks) between the back of the curb (or edge of the shoulder) and the front property line of adjoining parcels. In urban and urban core areas, the roadside is further divided into a series of zones that emphasize different functions, including frontage, throughway, furnishings and edge zones. Exhibits 2-6 and 2-7 provide further definition of these areas. In many communities the roadside also may include separate bicycle facilities (e.g., separated bicycle tracks, multiuse paths or exclusive cycle tracks). The function of roadside zones and the level of pedestrian and bicycle use of the roadside are directly related to the activities generated by the adjacent context and, in the case of bicycles, possible bicycle networks.

Exhibit 2-6. Components of an urban roadside.



2.11 Speed Management as a Design Goal

Transportation safety is not only about motorized vehicle safety; it also encompasses protecting vulnerable users. Setting safe, consistent and reasonable target speed limits is the first step in speed management and is important in order to reasonably accommodate and protect all roadway users. Transportation designers and practitioners employ various strategies to manage speeds on roadways, and speed limits are an integral part of many of those strategies; however, setting a posted speed limit on a street or road does not always yield acceptable vehicle operating speeds for all users or for the area context. Simply lowering the posted speed limit on a particular section of roadway does not ensure that motorists will lower the actual speed at which they travel. Therefore, transportation designers and operations engineers often employ other strategies, such as increased enforcement or physical speed-management countermeasures to encourage motorists to drive at a target speed that is more appropriate to the context and mix of users along that section of roadway.

As discussed in the previous section, selection of a posted speed is an operational decision for which the owner and operator of the facility is responsible. Anticipated operating and posted speeds should be considered in the selection of the design speed, but no regulation establishes a more direct relationship. FHWA's guidance memorandum also states that "In urban areas, the design of the street should generally be such that it limits the maximum speed at which drivers can operate comfortably, as needed to balance the needs of all users" (FHWA 2015c). This speed is typically referred to as the *target speed* for a facility.

In 2016, FHWA published a reference guide addressing speed management: *Integrating Speed Management within Roadway Departure, Intersections, and Pedestrian and Bicyclist Safety Focus Areas* (FHWA 2016d). This reference guide identifies the common issues regarding speeding-related pedestrian and bicycle crashes that were identified both by public agencies and by national crash data analysis results. Several speed-management strategies also were identified and recommended through agency interviews and published resources. These strategies recognize that every situation or location is unique, and that agencies exercise engineering judgment for determining the appropriate solution for specific crash concerns. Strategies suggested in the reference guide include the following techniques and improvements:

- Lighting;
- Rectangular rapid flash beacons;
- In-roadway warning lights;
- Public outreach and education;
- Raised median or refuge islands;
- Pedestrian hybrid beacon;
- Barriers to prevent unwanted crossings;
- Context-sensitive design;
- Road diets;
- [Accommodations for] pedestrians and bicyclists; and
- Bicycle-friendly rumble strips.

Roundabouts and various traffic calming techniques also have been used to assist in managing speeds along a roadway corridor. Other useful speed management resources to assist in designing streets and roads that serve a range of motorized and non-motorized users include:

- ***Engineering Speed Management Countermeasures: A Desktop Reference of Potential Effectiveness in Reducing Crashes*** (FHWA 2014a). This desktop reference source summarizes studies about the effectiveness of engineering countermeasures in reducing crashes and managing speed. An extensive table presents 52 separate techniques in the categories of vertical deflection, horizontal deflections/road narrowing, surface treatments and markings, vertical

delineation, dynamic signing and access controls. More than 100 references detail the effectiveness of these engineering countermeasures. The document also references studies where an increase in crashes was reported, as this information also is relevant in selection of countermeasures.

- **Speed Management: A Manual for Local Rural Road Owners (FHWA 2012b).** This document was developed to provide local road practitioners information on how to address speeding-related crashes through the implementation of a comprehensive speed management program. The document discusses several engineering countermeasures that can be used to influence driver speed choice. These countermeasures are grouped into three categories: traffic control devices, road and street design, and traffic calming:
 - **Traffic control devices.** “Installing or upgrading signs and pavement markings on an affected roadway can be a cost-effective measure to reduce speeding. Such improvements include advisory speed signs and pavement markings, speed activated signs, and optical speed bars” (FHWA 2012b).
 - **Road and street design.** “There are several modifications to the design of a road or street that can induce speed reductions and have other safety and operational benefits for all road users. These include reduced lane widths, road diets, center islands or medians, and roundabouts. Several of these countermeasures can be implemented on higher-speed roadways as well as lower-speed roads” (FHWA 2012b).
 - **Traffic calming.** “Traffic calming is the design or retrofit of a roadway to encourage uniform vehicle speeds and improve conditions for non-motorized users. Traffic calming is generally applied to roads with operating speeds of 30 mph or less. There are numerous identified traffic calming countermeasures that can be applied on different types of roads and streets, and these are identified in ITE’s *Traffic Calming: State of the Practice* [ITE 1999]. Some of the measures can also be applied in rural town contexts where pedestrian and/or bicycle activity may be a design issue” (FHWA 2012b).
- **NCHRP Report 737: Design Guidance for High-Speed to Low-Speed Transition Zones for Rural Highways (Torbic et al. 2012).** A common speeding-related problem occurs when a driver approaches a rural town or village from a higher-speed rural road. Gateway treatments (gateways) can be used in rural areas to capture the attention of drivers and inform them that the nature of the roadway is changing, and that, as a result, they should reduce their speed. A gateway is a “combination of traditional and nontraditional traffic control treatments, such as enhanced signing, lane reduction, colored pavements, pavement markings, experimental striping, gateway structures and traditional traffic calming techniques or other identifiable features” (Torbic et al. 2012).

Differences between the design standards and policies for high-speed and low-speed roadway environments complicate design of the transition zone. Many communities that want to use transition zones as gateways to the community have unrealistic expectations as to the magnitude of speed reduction. Transition zone design must attempt to meet many objectives while maintaining safety for all users. *NCHRP Report 737* addresses designing the transition from a high-speed rural highway to a lower-speed section, typically approaching a small town. Providing a methodology for assessing these highway sections and a catalog of potential treatments for addressing problems, this report is useful to geometric designers and traffic engineers responsible for these situations.

- **NCHRP Report 613: Guidelines for Selection of Speed Reduction Treatments at High-Speed Intersections (Ray et al. 2008).** Evaluating the effectiveness of treatments to reduce vehicle speeds at high-speed intersections, this report addresses geometric design features; signage and pavement markings; and stop-controlled, yield-controlled and uncontrolled approaches to signalized and unsignalized intersections. The guidelines apply to intersections with approach speeds of 45 mph or higher that are located primarily on suburban and rural roadways. The report focuses on public roadway intersections, but many of the principles discussed also can

be applied to private driveways that have public roadway-like features. The report does not address speeds on roadway segments outside the influence area of an intersection, but it does discuss the relationship between segment speed and speed within the intersection influence area.

2.12 Flexibility in Application of Design Elements and Criteria

Applying flexibility in the geometric design process to address multimodal needs requires knowledge of existing standards and guidelines, recognition of the range of options available, and understanding of how deviating from these may impact operations, safety and context. A flexible design approach uses existing geometric design criteria, controls and elements in creative and varied ways to solve unique design challenges. To accomplish this goal, the designer needs to have a broad understanding of variables, thresholds and available alternatives to achieve multiple objectives for all the modes served by the project.

Current national guidelines and standards provide significant levels of design flexibility. *Flexibility in Highway Design* (FHWA 1997) highlights the flexibility available to designers within existing standards and guidelines, and encourages them to apply this flexibility when designing roads to fit into the natural and human environment. *A Guide for Achieving Flexibility in Highway Design* (AASHTO 2004a) promotes the incorporation of sensitive community and environmental issues into the design of transportation facilities. The AASHTO flexibility guide shows roadway designers how to think flexibly, how to recognize the many available choices and options, and how to arrive at the best solution for the particular situation or context. It also emphasizes that flexible design need not entail a fundamentally new design process; rather, it can be integrated into the existing transportation culture.

The guidance in *Bicycle and Pedestrian Facility Design Flexibility* (FHWA 2013a) clearly states the agency's support for flexibility in the design of bicycle and pedestrian facilities. More recently, in May 2016 the AASHTO Standing Committee on Highways (SCOH) passed a resolution, titled *Direction on Flexibility in Design Standards*, which states that AASHTO should provide guidance to state departments of transportation (DOTs) and other users of the Green Book regarding flexibility in design; that this guidance should follow the AASHTO model of being research-based and peer-reviewed; that this guidance should assist in educating engineers and designers on the flexibility inherent in the Green Book, as well as new and additional guidance on specific design issues; and that this guidance should address designing in and for a multimodal transportation system.

In December 2015, Congress approved the current federal surface transportation funding legislation, titled Fixing America's Surface Transportation (FAST) Act (Pub. L. No. 114-94). The FAST Act contains several changes to design standards to increase flexibility and provide for greater accommodation of all highway users. Specific provisions address the following:

- **Design considerations for roadways that are part of the NHS.** The FAST Act now requires that designs *shall consider* (previously “may take into account”):
 - The constructed and natural environment of the area;
 - The environmental, scenic, aesthetic, historic, community, and preservation impacts of the activity;
 - Access for other modes of transportation; and
 - Cost savings by utilizing flexibility that exists in current design guidance and regulations.
- **Development of criteria for the NHS.** The FAST Act adds two new resources that DOTs must consider when developing criteria to implement the requirements for the NHS. These new resources for consideration are:

- The AASHTO *Highway Safety Manual* (HSM, AASHTO 2010); and
- The National Association of City Transportation Officials (NACTO) *Urban Street Design Guide* (NACTO 2013).
- **Design standard flexibility for localities.** Under the FAST Act, a locality may, with state approval, use a different roadway design publication than the state if:
 - The roadway is owned by the locality;
 - The roadway is not on the Interstate highway system;
 - The locality is the direct recipient of federal funds for the project;
 - The publication is recognized by FHWA and adopted by the locality; and
 - The design complies with all other applicable federal laws.
- **Accommodation of non-motorized users.** The FAST Act requires DOTs to encourage states and metropolitan planning organizations (MPOs) to adopt design standards for federal surface transportation projects that provide for the safe and adequate accommodation (as determined by the state) of all users of the surface transportation network, including motorized *and* non-motorized users in all stages of project planning, development and operation. Additionally, by 2017 (no later than 2 years after the enactment of the FAST Act), DOTs were required to release reports identifying examples of state laws and policies in this area and examples of best practices.

2.12.1 Flexibility in Existing Design Policy, Standards and Guidelines

Roadway designers have the responsibility to understand what flexibility is allowed and encouraged in applying existing standards and guidelines. The documents listed in this section are typically used by agencies to develop design guidance for the selection of geometric design controls and criteria, traffic controls and traffic analysis.

- The Green Book (AASHTO 2011a) and AASHTO's supplemental guides for roadside design, pedestrian facility design, bicycle facility design and others are recognized as the national guidance for the design of roadways and paths. The Green Book has been adopted by FHWA as the standard for the design of projects on the NHS. Some states have adopted these AASHTO guides in their entirety, whereas other states have used them as the basis to create their own design guidance. The Green Book provides the most comprehensive guidance on geometric design and is a key resource used by designers.
- The HSM (AASHTO 2010) provides a science-based technical approach for safety analysis of design and operation of streets and highways. The HSM emphasizes the use of analytical methods to quantify the safety effects of decisions in planning, design, operations and maintenance. The HSM provides tools to conduct quantitative safety analyses, allowing safety to be quantitatively evaluated alongside other transportation performance measures such as traffic operations, environmental impacts and construction costs. The HSM also provides methods for developing an effective roadway safety management program and evaluating its effects, a predictive method to estimate crash frequency and severity, and a catalog of crash modification factors (CMFs) for a variety of geometric and operational treatment types, backed by robust scientific evidence. The HSM is written for practitioners at the state, county, MPO or local level.
- The MUTCD (FHWA 2009b) sets the national standard for traffic control devices, including signing, pavement markings and traffic signals. The MUTCD is included by reference in the Code of Federal Regulations (CFR) and is recognized as the national standard for all traffic control devices installed on any street, highway, bikeway or private road open to public travel.
- TRB's *Highway Capacity Manual, Sixth Edition: A Guide for Multimodal Mobility Analysis* (HCM) (TRB 2016b) is the national guideline for analyzing traffic operations. The HCM

6th Ed. does not establish a legal standard, but it provides guidance on techniques to analyze various modes of traffic.

2.12.2 Flexibility in the AASHTO Green Book

The Green Book emphasizes the need for a comprehensive design approach that requires the consideration of contexts, all modes of travel and the use of engineering judgment. The following statement from the introduction to the Green Book highlights how the guidelines allow for flexibility (AASHTO 2011a):

The intent of this policy is to provide guidance to the designer by referencing a recommended range of values for critical dimensions. Good highway design involves balancing safety, mobility, and preservation of scenic, aesthetic, historic, cultural, and environmental resources. This policy is therefore not intended to be a detailed design manual that could supersede the need for the application of sound principles by the knowledgeable design professional. Sufficient flexibility is permitted to encourage independent designs tailored to particular situations.

Throughout, the Green Book also references the need for the designer to understand land use context and the needs of all facility users in the geometric design process. Two excerpts highlight that recurring guidance:

Emphasis is placed on the joint use of transportation corridors by pedestrians, cyclists and public transit vehicles. Designers should recognize the implications of this sharing of the transportation corridors and are encouraged to consider not only vehicular movement, but also movement of people, distribution of goods, and provision of essential services. A more comprehensive transportation program is hereby emphasized.

and

... the designer should keep in mind the overall purpose that the street or highway is intended to serve, as well as the context of the project area.

Each document stresses the need for flexibility in the design process and encourages the designer to employ engineering judgment and consider context when designing roadways. However, the designer must realize that no publication can address every real-world situation; each project contains unique combinations of community goals, context and mix of users. Keeping this reality in mind, a designer who understands the engineering principles behind the design guidance being used can recognize the degree of flexibility that can be applied safely and effectively to a project design.

Several additional publications provide information on best practices and innovations in multimodal design. These publications include:

- *Achieving Multimodal Networks: Applying Design Flexibility and Reducing Conflicts* (FHWA 2016a);
- *Designing Walkable Urban Thoroughfares: A Context Sensitive Approach* (ITE 2010a);
- *Urban Bikeway Design Guide* (NACTO 2014); and
- *Urban Street Design Guide* (NACTO 2013).

FHWA has expressed support of the use of these additional resources and has emphasized that they can be used to inform the planning and design process. Several government agencies have adopted or endorsed these publications and are using them as resources in their roadway and street design processes.

2.13 Design Exceptions

In 1985, FHWA established a policy regarding what were considered “controlling” criteria for design. Thirteen (13) criteria were identified as having substantial importance to the operational and safety performance of any roadway such that special attention should be paid to them in

design decisions. For any roadway on the NHS, FHWA required a formal written design exception if any of these 13 design criteria were not met.

Although all of the criteria contained in the adopted standards are important design considerations, recent research has shown that they do not equally affect the safety and operations of a roadway, and therefore do not require the same level of administrative control. Based on these findings and on the recommendations of *NCHRP Report 783: Evaluation of the 13 Controlling Criteria for Geometric Design* (Harwood et al. 2016), in 2016 FHWA reduced the number of controlling criteria from 13 to 10, applicable to projects on the high-speed roadways on the NHS (i.e., Interstate highways, other freeways, and roadways with design speed ≥ 50 mph). Of the 10 remaining criteria, only two criteria—design loading structural capacity and design speed—now apply to low-speed roadways on the NHS (45 mph or lower).

The 10 controlling criteria for projects on the NHS with design speeds at and above 50 mph are:

1. Design speed;
2. Lane width;
3. Shoulder width;
4. Horizontal curve radius;
5. Superelevation rate;
6. Stopping sight distance (SSD);
7. Maximum grade;
8. Cross slope;
9. Vertical clearance; and
10. Design loading structural capacity.

Subject to approval by FHWA (or on behalf of FHWA if a state transportation agency has assumed the responsibility through a Stewardship and Oversight Agreement), design exceptions are required for projects on the NHS only when the controlling criteria described above are not met. The level of analysis should be commensurate with the complexity of the project. As documented in the *Federal Register*, FHWA expects documentation of design exceptions to include (81 Fed. Reg. 87 [5 May 2016]):

- Specific design criteria that will not be met.
- Existing roadway characteristics.
- Alternatives considered.
- Comparison of the safety and operational performance of the roadway and other impacts such as right-of-way, community, environmental, cost, and usability by all modes of transportation.
- Proposed mitigation measures.
- Compatibility with adjacent sections of roadway.

Design Speed and Design Loading Structural Capacity are fundamental criteria in the design of a project. Exceptions to these criteria should be extremely rare and FHWA expects the documentation to provide the following additional information:

- Design Speed exceptions:
 - Length of section with reduced design speed compared to overall length of project
 - Measures used in transitions to adjacent sections with higher or lower design or operating speeds.
- Design Loading Structural Capacity exceptions:
 - Verification of safe load-carrying capacity (load rating) for all State unrestricted legal loads or routine permit loads, and in the case of bridges and tunnels on the Interstate, all Federal legal loads.

The FHWA encourages agencies to document all design decisions to demonstrate compliance with accepted engineering principles and the reasons for the decision.

Deviations from the criteria contained in the standards for projects on the NHS that are not considered to be controlling criteria should be documented in accordance with state laws, regulations, directives and safety standards. Depending on state laws and risk management practices,

states can determine their own level of documentation and may adopt policies that are more restrictive than the FHWA policy outlined above.

FHWA also encourages agencies to work with stakeholders “to develop context-sensitive solutions that enhance communities and provide multiple transportation options to connect people to work, school, and other critical destinations” (81 Fed. Reg. 87 [5 May 2016], p. 27189).

2.14 Liability Considerations

Many designers are concerned about both personal and agency liability when applying flexibility in the roadway design process. Because of these concerns, some designers may rigidly apply conservative, vehicle-based design criteria to the detriment of other modes. Without considering the safety, accessibility and convenience of other roadway users, adherence to the most conservative design values may not constitute reasonable care on behalf of the designer. A balanced geometric design approach will consider not only vehicles, but also pedestrians, bicyclists and transit users.

As noted by FHWA, “. . . a designer who deviates from established design guidance is not necessarily negligent, particularly if the designer follows and documents a clear process, using engineering judgment, when dealing with design exceptions, and experimentation” (FHWA 2016a). Succeeding with a flexible approach to geometric design typically requires some combination of engineering judgment, documentation and experimentation.

2.14.1 Engineering Judgment

Engineering judgment requires an understanding of engineering principles and the assumptions and relationships inherent in adopted standards and guidelines. It also requires knowledge and understanding of community goals, context and site-specific conditions for the subject project. A designer should understand the impacts of applying various design criteria and elements (and their combinations). Using engineering judgment, the designer determines the most appropriate applications of—or changes from—conventional guidance to achieve a design solution that considers all factors.

Ideally, designers will consider the safety and comfort of all legal users in current and future design-year conditions along with constraints and needs related to limited space, resources, and funding. Designs also should account for the scenic, historic, aesthetic, and cultural values of the surrounding community, and any goals the community may have for the project areas.

As crucial contributors to the design process, stakeholders can and should influence the design engineer’s judgment. The opinions, needs and desires of neighborhoods, property owners, facility user groups and the public at large are all important. Ultimately, it is the designer’s responsibility to consider the opinions of various stakeholder groups while also educating them about the range of possible design options, solutions and outcomes for the project.

2.14.2 Documentation

Designers should document their design decisions, especially those that involve the application of innovative, flexible, and creative approaches. Developing reports, studies and other types of documentation that explain the rationales used to create specific design solutions can be particularly important if those solutions vary from typical approaches or established design guidance. Depending on the facility type, design speed and other factors, formal design exceptions

also may be required. Documenting design decisions is a required component of the design exception process.

2.14.3 Experimentation

Liability concerns need not prevent designers from applying innovative and unique approaches that, in their engineering judgment, are reasonable solutions to a particular design challenge. In some situations, formal experimentation may be necessary to support the use of design treatments and safety countermeasures. This formal approach is typically applied for the design or use of traffic control devices that are not specifically included in, or compliant with, the MUTCD (FHWA 2009b).

Section 1A.10 of the MUTCD outlines a formal experimentation process that includes evaluation and follow-up adjustments to the design (including removal of the design) as needed. The experimentation process helps drive the advancement of the design practice and the adoption of new traffic control devices and their applications in the MUTCD. The experimentation process has resulted in the ability to apply new types of traffic control devices such as pedestrian hybrid beacons, bicycle signals, and colored pavement markings, all of which are important to providing safe and accessible accommodation of pedestrians and bicyclists in certain settings.

2.14.4 Liability Defense Practices

NCHRP Legal Research Digest 57: Tort Liability Defense Practices for Design Flexibility (Parker 2012) presents the results of a study of tort liability defense practices and cases involving the exercise of discretion in roadway design practices. This research digest provides the designer with a framework for determining successful strategies to use when defending design decisions made using flexibility driven by multimodal needs, context-sensitive solutions (CSS), practical solutions and other related initiatives. The digest explores the concept of discretion as a defense to government tort liability, and defending flexible design decisions based on the designers' and policymakers' discretion may be described by terms such as governmental immunity, official immunity, design immunity, or policy immunity.

Existing law is relevant to analysis of tort legal defenses available to protect the decisions inherent in CSS. Many roadway design agencies have adopted flexible design policies and the use of CSS principles or related concepts to encourage flexibility in design decision making. The digest's suggested processes for documenting design decisions, articulating clearly the various factors considered in making a decision with a focus on decisions that involve design exceptions, should be of great help to designers, their agencies and others responsible for exercising such judgment and decisions.

2.15 Considerations for Users with Disabilities

As detailed in a joint document from the U.S. Department of Justice (U.S. DOJ) and U.S.DOT regarding Title II requirements of the Americans with Disabilities Act (ADA), state and local governments must "ensure that persons with disabilities have access to the pedestrian routes in the public right-of-way." An important part of this requirement is the obligation to provide curb ramps where street level pedestrian walkways cross curbs whenever streets, roadways or highways are *altered* (U.S. DOJ and U.S.DOT 2013):

An alteration is a change that affects or could affect the usability of all or part of a building or facility. Alterations of streets, roads, or highways include activities such as reconstruction, rehabilitation,

resurfacing, widening, and projects of similar scale and effect. Without curb ramps, sidewalk travel in urban areas can be dangerous, difficult, or even impossible for people who use wheelchairs, scooters, and other mobility devices. Curb ramps allow people with mobility disabilities to gain access to the sidewalks and to pass through center islands in streets. Otherwise, these individuals are forced to travel in streets and roadways and are put in danger or are prevented from reaching their destination; some people with disabilities may simply choose not to take this risk and will not venture out of their homes or communities.

The ADAAG were adopted as the design standards for making facilities accessible to all pedestrians (U.S. Access Board 2002). These guidelines, and more recently adopted updates, include requirements such as limiting criteria for clear passage, turning spaces, longitudinal and cross slopes, ramps with handrails, curb ramps between sidewalks and street crossings, and handicap parking spaces. However, the ADAAG are more applicable to building and site construction than they are to the longitudinal public right-of-way. Designers and agencies have been left to translate the ADAAG standards to highways and streets and make judgments on issues not fully addressed by the standards.

The U.S. Access Board published the PROWAG in 2011 and a supplemental notice with guidance on shared-use paths in 2013 (U.S. Access Board 2011, 2013).

The PROWAG will become enforceable as a standard only after the U.S. Access Board publishes a final rule and after the U.S. DOJ and/or the U.S.DOT adopt the final guidelines into their respective ADA and Section 504 regulations. At publication of this Guide, the U.S. Access Board had not issued a final PROWAG rule. Currently the U.S. DOJ's *2010 ADA Standards for Accessible Design* (2010 ADA Standards) and U.S.DOT's *2006 Americans with Disabilities Act (ADA) Standards for Transportation Facilities* (2006 ADA/Section 504 Standards) for recipients of federal financial assistance from U.S.DOT provide enforceable standards applicable to the public right-of-way (U.S. DOJ 2010a, U.S.DOT 2006).

Where the 2010 ADA Standards or the 2006 ADA/Section 504 Standards do not address a specific issue in the public right-of-way, FHWA encourages public entities to look to the draft PROWAG for best practices. Several jurisdictions have chosen to apply the draft PROWAG as an alternative to, or equivalent facilitation for, the 2010 ADA Standards because they provide more specific coverage of accessibility issues in the public-right-of-way. It is advised that jurisdictions that have adopted the draft PROWAG as their standard consistently apply all provisions of the draft PROWAG.

With these new guidelines, early consideration of accessible design alternatives will be more imperative than ever. Requirements for crosswalks will affect horizontal and vertical alignments and drainage at intersections. Curb ramps may require additional rights-of-way at intersection corners. Utilities may need to be removed or relocated to provide proper widths and clearances. When designers leave consideration of accessible pedestrian facilities until later in the design, they may severely limit their opportunities to develop a design that best meets the needs and provides the best functionality for all users.

Because these ADA guidelines are based on civil rights law, designers do not have the same latitude to vary from them as they would other design standards and guidelines. Under extraordinary conditions with limiting terrain or other severe constraints, designers may determine that meeting the guidelines is impracticable, but they must still design the facilities to conform with accessibility standards to the maximum extent feasible.

This Guide cites the draft PROWAG in anticipation of final PROWAG being adopted as the enforceable standard in the near future. Public entities and/or recipients of federal financial assistance are responsible for complying with the current ADA and Section 504 accessibility standards and/or demonstrating equivalent facilitation.

2.16 Considerations for Bridges and Other Structures

Bridges are key components of any transportation network, particularly for pedestrian and bicycle networks in urban and suburban areas. They often are the only way for all modes to travel across natural obstacles (rivers, ravines), railroads, freeways and grade-separated crossings. In addition, because the typical lifespan of a bridge is much longer than that of a typical section of road, it is important to address considerations for bicycle and pedestrian connections during bridge construction and reconstruction projects. It is important that bridges safely accommodate pedestrians and bicyclists; without such accommodation, these vulnerable users may try to use vehicle lanes to cross the structure, which is unsafe for pedestrians and may be unsafe for some bicyclists. A bridge without safe walking and bicycling accommodation also can create lengthy detours that make the entire trip impractical for pedestrians and bicyclists.

The United States Code (U.S.C.) addresses accommodations on bridges for non-motorized users. Specifically, 23 U.S.C. 217(e) emphasizes the need to address bicycle accommodations during bridge replacement projects:

In any case where a highway bridge deck being replaced or rehabilitated with Federal financial participation is located on a highway on which bicycles are permitted to operate at each end of such bridge, and the Secretary determines that the safe accommodation of bicycles can be provided at reasonable cost as part of such replacement or rehabilitation, then such bridge shall be so replaced or rehabilitated as to provide such safe accommodations.

Bridge projects can be used to make critical new connections in pedestrian and bicycle networks. In some locations, a truly cohesive network may only exist with bridge connections for non-motorized users. In other areas, a new bridge may provide a more direct route than the ones currently available. For existing bridges, improving the safety and comfort of non-motorized users may require them to be retrofitted with more appropriate, separated facilities.

Providing pedestrian and bicycle accommodation during initial construction generally costs less than retrofitting later. Current design guidance generally provides adequate flexibility on how to best accommodate these users in bridge design projects. Safe pedestrian access often can be implemented at the same time as bicycle accommodations and should be provided on bridges whenever possible. To avoid creating barriers, bridges also should accommodate bicycle and pedestrian facilities traveling under them.

The U.S.DOT's 2010 Policy Statement on Bicycle and Pedestrian Accommodation Regulations and Recommendations urges transportation agencies and local communities to go beyond minimum design standards and requirements to create safe, attractive, sustainable, accessible, and convenient walking and bicycling networks. With regard to "integrating bicycle and pedestrian accommodation on new, rehabilitated and limited-access bridges," the policy statement "encourages bicycle and pedestrian accommodation on bridge projects including facilities on limited-access bridges with connections to streets or paths. . . . It is more effective to plan for increased usage than to retrofit an older facility. Planning projects for the long-term should anticipate likely future demand for bicycling and walking facilities and not preclude the provision of future improvements" (U.S.DOT 2010).

AASHTO also supports the provision of pedestrian and bicycle accommodation on and across bridges as noted in excerpts from published design guides (AASHTO 2014b, AASHTO 2004b):

Bridges, viaducts, and tunnels should accommodate bicycles . . . there are numerous examples of limited-access highway bridges that cross major barriers (such as wide waterways) that incorporate a shared-use path for bicyclists and pedestrians. The absence of a bicycle accommodation on the approach roadway should not prevent the accommodation of bicyclists on the bridge or tunnel.

Provisions should always be made to include some type of walking facility as a part of vehicular bridges, underpasses, and tunnels, if the facility is intended to be part of a pedestrian access route.

2.17 Coordination with Stormwater and Green Infrastructure

FHWA estimates that about 35 percent of U.S. roads are located in urban areas. Urban areas also include many other types of impervious surfaces, such as roofs, sidewalks and parking lots. Although all these surfaces contribute to stormwater runoff, the effects and necessary mitigation of the various types of surfaces can vary significantly. Of these surfaces, streets and roads present significant urban stormwater runoff and generally carry the most potential as sources of pollution. As a result, streets and roadways in urban areas offer one of the greatest opportunities to apply advanced stormwater management techniques. These techniques, which often are applied in roadway border areas, must be coordinated with provisions for pedestrian and bicycle facilities. Stormwater management and other “green” infrastructure applications often are used to increase the separation between the traveled way and other roadside users.

Green infrastructure, a cost-effective and resilient approach to managing wet weather impacts, can provide many community benefits. Traditional street design has directed “gray” stormwater runoff from impervious surfaces into storm sewer systems (using gutters, drains and pipes) that move urban stormwater away from the built environment and discharge directly into surface waters, rivers and streams. In contrast, “green” infrastructure is designed to reduce, capture, and treat stormwater at its source (where the rain falls). Green street techniques encourage the interaction of stormwater with soil and vegetation to promote infiltration and retention. Treatments can incorporate a wide variety of design elements such as street trees, permeable pavements, bioretention and swales. Although the design and appearance of green streets will vary, the functional goals are typically the same.

In urban and suburban areas, streets and roadways present many opportunities for coordinated green infrastructure use. Many agencies have begun to capitalize on the benefits gained by introducing green infrastructure in transportation projects. To assist agencies in applying these techniques, the EPA developed *Managing Wet Weather with Green Infrastructure Municipal Handbook: Green Streets* (U.S. EPA 2008). Following is a sampling of the stormwater management approaches presented in the Green Streets handbook (U.S. EPA 2008):

Alternative Street Designs (Street Widths)

A green street design begins before any BMPs [best management practices] are considered. When building a new street or streets, the layout and street network must be planned to respect the existing hydrologic functions of the land (preserve wetlands, buffers, high-permeability soils, etc.) and to minimize the impervious area. If retrofitting or redeveloping a street, opportunities to eliminate unnecessary impervious areas [such as using narrow travel and parking lanes] should be explored.

Swales

Swales are vegetated open channels designed to accept sheet flow runoff and convey it in broad shallow flow. The intent of swales is to reduce stormwater volume through infiltration, improve water quality through vegetative and soil filtration, and reduce flow velocity by increasing channel roughness. In the simple roadside grassed form, they have been a common historical component of road design. Additional benefit can be attained through more complex forms of swales, such as those with amended soils, bioretention soils, gravel storage areas, underdrains, weirs, and thick diverse vegetation.

Bioretention Curb Extensions and Sidewalk Planters

Bioretention is a versatile green street strategy. Bioretention features can be tree boxes taking runoff from the street, indistinguishable from conventional tree boxes. Bioretention features can also be attractive attention-grabbing planter boxes or curb extensions. Many natural processes occur within bioretention cells: infiltration and storage reduces runoff volumes and attenuates peak flows; biological and chemical reactions occur in the mulch, soil matrix and root zone; and stormwater is filtered through vegetation and soil.

Permeable Pavement

Permeable pavement comes in four forms: permeable concrete, permeable asphalt, permeable interlocking concrete pavers, and grid pavers. Permeable concrete and asphalt are similar to their impervious counterparts but are open graded or have reduced fines and typically have a special binder added.

Sidewalk Trees and Tree Boxes

From reducing the urban heat island effect and reducing stormwater runoff to improving the urban aesthetic and improving air quality, much is expected of street trees. Street trees are even good for the economy. Customers spend 12% more in shops on streets lined with trees than on those without trees.

Sources of Additional Information

This publication supplements the sources listed at the end of Chapter 1.

Harwood, D. W., et al. 2016. *NCHRP Report 783: Evaluation of the 13 Controlling Criteria for Geometric Design*. Transportation Research Board of the National Academies, Washington, D.C.



CHAPTER 3

Balancing User Performance in Low- and Intermediate-Speed Environments

3.1 Performance for Multimodal Projects

Performance measures promote informed decision making by relating community goals to the measurable effects of transportation investments. Key steps in developing performance measures are (1) deciding what to measure to capture the current state of the system, (2) setting targets to improve those measures and (3) using the measures to evaluate and compare the effects of proposed project alternatives.

For a project, performance measures can include a wide range of multimodal criteria (e.g., capacity, mobility, safety, accessibility, comfort, reliability). Performance measures also can include unique operations measures that are identified for each mode by user or mode (e.g., travel speed, delay, crash potential, convenience, accessibility, LOS, QOS). From a purely safety perspective, performance measures for each mode may be identified, such as expected number of total crashes or crashes by severity, expected number of fatalities and injuries (by severity), expected number of crashes by collision type, crash exposure, and so forth. From a sustainable transportation perspective, performance measures could include transit accessibility/productivity, bicycle/pedestrian mode share, vehicle-miles traveled (VMT) per capita, levels of “bikeability” or “walkability,” aesthetics, air quality impacts, and so forth.

Many of these measures need to be classified according to whether they are multimodal or mode-specific, and guidance is needed on how the measures should differ depending on the roadway speed range (i.e., low, intermediate, or high speed), roadway functional classification and context.

For street and road projects that will blend multimodal users in low- and intermediate-speed environments, it is advised that performance measures be developed for all existing and projected users as well as for all identified sustainable and community goals. Safety should always be a key element of this analysis; the risk of fatal or severe injury to non-motorized users is significant in all vehicle environments but especially in higher speed environments (above 25 mph). Only through carefully defined performance metrics can the designer understand and project the impacts of design choices on all modes in a project.

3.1.1 Increased Demand for Pedestrian, Bicycle and Transit Performance Measures

As more agencies design transportation projects that include improvements for walking, bicycling and transit accommodation, they are increasing their efforts to understand and establish performance measures and metrics that address all these modes. Most transportation agencies have routinely relied on vehicle-based performance metrics from the HCM to assess the effectiveness of improvement designs for motorized travel, but the evolving tools and processes

available to assess the needs and service levels of non-motorized users have been more elusive and ultimately difficult to use.

Capacity, LOS, delay and stops are easily applied to define and assess vehicular performance for a planned roadway, but no predefined set of performance metrics can fully describe the safety and mobility complexities that exist given the interrelationships that exist between and among modes in the right-of-way. In a constrained funding environment, it is critical to be able to identify the project scope and which investments will provide the highest level of benefit to the most users in a roadway corridor, segment or intersection. Consequently, more agencies are applying multiple transportation performance measures—in various ways and using various scales—throughout the transportation design process.

Performance management also plays a central role in federal, state, regional and local transportation planning, funding and design. Since 2015, the FAST Act “has required state DOTs and MPOs to consider non-motorized users in long-range statewide transportation plans (LRSTP) and metropolitan transportation plans (MTP).” The FAST Act also stipulates that these plans must include a description of the performance measures and performance targets used in assessing the performance of the transportation system and a system performance report evaluating the condition and performance of the transportation system.

This Guide is intended to help designers better understand, select and apply performance measure tools for a variety of project design elements, controls and criteria. Although some transportation performance measures are useful for tracking and measuring progress toward related, broad community goals such as health and economic development, the measures addressed in these guidelines focus on mobility, accessibility, QOS, safety and reliability outcomes from design choices. Critical steps in performance management are (1) deciding what to measure to capture the current condition of the facility from all user perspectives, (2) setting targets that improve those measures, and (3) using the measures to evaluate and compare the effects of project design alternatives.

3.2 Assessing Performance, LOS and QOS for All Users

Conventional roadway design has traditionally attempted to provide the highest practical vehicular LOS for a project. Conversely, designing roadways for all users takes vehicle traffic projections and LOS into account but also evaluates LOS and QOS for non-motorized users. It then balances the needs of all legal users of the roadway, and may even emphasize one or more users over others depending on the context, purpose and need of the project (e.g., a project may reduce vehicle lanes to accommodate bicycle lanes, on-street parking or wider sidewalks).

While vehicular capacity and LOS certainly play an important role in selecting design criteria, they are only two of numerous factors a designer should consider and prioritize in the design of roads and streets with a mix of users. Often in urban and urban core areas, roadway capacity is considered a lower priority than factors such as non-motorized user safety and higher levels of accessibility for transit, pedestrian or bicycle travel, facilitating economic development, or preserving historical features. In those situations, the community may consider lower levels of vehicle service (e.g., higher levels of vehicle inconvenience or congestion) acceptable. LOS and QOS for all users often is a priority project design objective for local agencies or communities, but it may require variances or exceptions from the adopted design or performance standards of partner agencies (e.g., FHWA or a state DOT).

The geometric design of a street or roadway project typically begins with an assessment of the purpose and need of the project. This purpose and need can be determined informally or formally through environmental process documentation. Normally established goals and

outcomes will address, at some level, the desired performance of the new or redesigned facility. Traditionally, these goals and outcomes have focused on the LOS and safety provided to motorized vehicles; more recently, both the LOS and QOS are being considered *for all legal users* of that facility, using a wide range of possible performance measures.

3.2.1 Performance Measures

From an operational perspective, the LOS criterion for motorized vehicles from procedures defined in the HCM traditionally has served as the primary performance measure for evaluating the quality of alternative roadway designs. However, approaches to assessment of LOS have been impacted by:

- Performance-based design research;
- Development of alternative approaches to multimodal LOS;
- Publication of the HSM (AASHTO 2010) and supplementary information;
- Numerous state and local guidelines for complete street design; and
- Extensive information on context-sensitive design solutions and design flexibility.

As a result, a recognized need exists to identify performance measures that can be used to evaluate the design alternatives for a roadway project based on how it meets the overall needs and safety of all users and modes: automobile/truck, pedestrian, bicyclist and transit user. Additionally, given the interactions of the various modes in a project, improvements made to the LOS or QOS for one mode may improve or lower the LOS or QOS for one or more of the other modes.

Today, geometric designers can use a wide variety of tools to assess the performance, LOS and QOS for all modes operating on all types of roadways, including low- and intermediate-speed streets. These tools range from detailed quantitative processes in the HCM that require field data collection and mathematical analysis, to more simple and qualitative methods such as the bicycle level of service (BLOS) model (Sprinkle Consulting 2007) and the Pedestrian Environmental Quality Index (PEQI) developed by the San Francisco Department of Public Health (San Francisco Department of Public Health 2012). The HSM is providing ever-increasing guidance to designers on the safety implications of design choices affecting all modes. These and the other available tools offer designers choices for evaluating street design alternatives and guide future improvement decisions. However, the ability of most of these tools to measure the effectiveness of *combinations* of multimodal design accommodations, including evolving innovative treatments such as separated bicycle tracks and bicycle-protected intersections, has been limited. As a result, many agencies and designers employ a variety of tools and strategies in assessing LOS and QOS, and often employ a wide range of performance-based design measures beyond LOS and QOS.

3.2.2 Current Practice

The leading geometric design LOS tool used by roadway design agencies has traditionally been the HCM (2010 edition) and its analysis software. In response to the increasing need to estimate performance measures related to pedestrian, bicycle and transit facilities, as well as their interactions with vehicle facilities, the HCM 6th Ed. (subtitled *A Guide for Multimodal Mobility Analysis*) provides several new and improved assessment tools and methods. Chapters 16–23 of the HSM include methods for assessing non-motorized modes and their interactions with vehicular traffic, whereas Chapter 24 provides methods for analyzing off-street pedestrian and transit facilities. Chapter 15 provides a methodology for evaluating bicycle operations on multilane and two-lane highways. The HCM considers the effects of transit presence along urban streets within its multimodal analysis framework. A companion document to the HCM, the *Transit Capacity and*

Quality of Service Manual (TCQSM), now in its third edition, focuses on the evaluation of transit facilities (Kittelson and Associates, Inc., et al. 2013).

Many agencies and design professionals have considered the 2010 HCM analysis to be the most comprehensive and thorough LOS procedure available, but many users have also expressed concern with the difficulty in using this tool to analyze multimodal level of service (MMLOS) and concerns about the relationship of its bicycle, pedestrian and transit LOS and QOS findings to actual field conditions and user group perceptions. In practice, the HCM tools have been used routinely for evaluating and designing the motorized-vehicle elements of street and roadway design projects, whereas the multimodal analysis tools have been used much less frequently. Most design professionals know that these HCM tools exist, but the multimodal analysis methods appear to have been selectively used for larger, more complex projects that involve major investment (e.g., lengthy corridor improvements). The newer multimodal analysis guidance included in the HCM 6th Ed. may be considered more effective and used more often by designers to evaluate multimodal design alternatives. Given the relatively short time the HCM 6th Ed. has been available for use, however, little has been published by practitioners about the real-world applicability and ease of use of the new multimodal analysis tools.

The designer also must consider how the selected LOS, QOS and other performance measures for a project should be used collectively to evaluate alternative geometric design options. A full range of methodologies may be considered, from simple qualitative approaches to more complex approaches (e.g., combining multiple performance measures into a combined weighted index for evaluation purposes). Additionally, the impact of a design choice on infrequent but important users (e.g., emergency response vehicles, commercial service vehicles, large freight trucks) needs to be factored into the overall procedures for evaluating design alternatives. Similarly, design choices can have significant impacts on various users traveling by other modes. For example, the mix of pedestrians (e.g., children, adults of various ages, and persons with disabilities) may vary by location, and design choices may need to incorporate ADA and other guidelines accordingly. Similarly, the types of bicyclists (e.g., commuter, school, recreational, etc.) and the effectiveness of different types and levels of transit service (e.g., local bus, bus rapid transit [BRT], trolley/streetcar, light rail, and so forth) need to be considered.

3.2.3 Evolving Guidance for Assessing Multimodal Performance in the Design Process

In recent years, the profession has developed an increasing amount of literature and research to improve performance-based planning and design for all modes served by transportation projects and address the needs of all users. Many agencies and project designers have been challenged to stay abreast of this rapidly evolving guidance and incorporate it properly into their agency policies, standards and processes.

The leading guidance documents currently available to designers in assessing and guiding design for multimodal performance are:

- ***Guidebook for Developing Pedestrian and Bicycle Performance Measures* (FHWA 2016c).** As described in the report abstract,

[t]his guidebook is intended to help communities develop performance measures that can fully integrate pedestrian and bicycle planning in ongoing performance management activities. It highlights a broad range of ways that walking and bicycling investments, activity, and impacts can be measured and documents how these measures relate to goals identified in a community's planning process. It discusses how the measures can be tracked and what data are required, while also identifying examples of communities that are currently using the respective measures in their planning process.

The FHWA guidebook expands the concept of performance measures specifically for pedestrian and bicycle transportation and identifies a toolbox of 30 specific performance measures mapped to seven broader project goal categories: connectivity, economic, environment, equity, health, livability and safety. The guidebook notes that pedestrian and bicycle transportation are considered “critical to each of these goal categories, and many performance measures are useful in characterizing a community’s transportation system’s ability to further the community goals.” The FHWA guidebook highlights the “universe of possibility” for pedestrian and bicycle performance measures, enabling communities at the local, regional and state levels to select from among these measures and “develop a performance management strategy that is tailored to their context and unique needs” (FHWA 2016c).

Many transportation agencies focus on transportation-specific goals (e.g., mobility and accessibility), which can be used to describe the transportation system and help set policies and priorities. However, individual transportation goals and performance measure categories often relate to more than one of the broader community goals. As discussed in the guidebook, accessibility helps connect buyers and sellers (thus contributing to economic goals) while also supporting a community’s livability. The guidebook also lists transportation measures that support one or more community goals (FHWA 2016c):

- Accessibility: Refers to access for people with disabilities to programs, services, and activities.
 - Compliance: Conforming to a requirement, e.g., a statute or regulation.
 - Demand: The amount of existing and potential future walking and bicycling activity.
 - Reliability: Refers to the degree of certainty and predictability in travel times on the transportation system.
 - Mobility: The ability of all users to travel or move from place to place.
 - Infrastructure: All the relevant elements of the environment in which a transportation system operates, including streets, signals, bridges, transit, bike facilities, shared-use paths, and sidewalks.
- ***Highway Capacity Manual (HCM), Sixth Edition: A Guide for Multimodal Mobility Analysis (TRB 2016b)***. The HCM 6th Ed. provides methods for quantifying highway capacity and is described on the Transportation System Preservation Technical Services Program (TSP-2) webpage as follows (TSP-2 2016):

In its current form, it serves as a fundamental reference on concepts, performance measures, and analysis techniques for evaluating the multimodal operation of streets, highways, freeways, and off-street pathways. The 6th Edition incorporates the latest research on highway capacity, quality of service . . . and travel-time reliability and improves the HCM’s chapter outlines. The objective is to help practitioners applying HCM methods understand their basic concepts, computational steps, and outputs.

. . . HCM has evolved over the years to keep pace with the needs of its users and society, as the focus of surface transportation planning and operations in the United States has moved from designing and constructing the Interstate highway system to managing a complex transportation system that serves a variety of users and travel modes. Providing mobility for people and goods is transportation’s most essential function.

It consists of four dimensions:

- Quantity of travel, the magnitude of use of a transportation facility or service;
- Quality of travel, users’ perceptions of travel on a transportation facility or service with respect to their expectations;
- Accessibility, the ease with which travelers can engage in desired activities; and
- Capacity, the ability of a transportation facility or service to meet the quantity of travel demanded of it.

Chapters in the HCM 6th Ed. also provide methods that address the increasing need to estimate performance measures related to pedestrian, bicycle and transit facilities and the interactions of these modes with vehicles. Chapters 15–23 and Chapter 25 address analyzing off-street pedestrian and transit facilities, evaluating bicycle operations on multilane and two-lane highways, and assessing non-automobile modes and their interactions with vehicular traffic.

Using the HCM 6th Ed. for pedestrian and bicycle analysis on urban streets can require significant data collection and analysis. The guidebook provides three pedestrian performance measures for urban street segments and facilities: (1) space, reflecting the density of pedestrians on a sidewalk, (2) speed, reflecting intersection delays, and (3) a pedestrian LOS (PLOS) score, reflecting pedestrian comfort with the walking environment (TRB 2016b). Exhibit 3-1 lists the data required for these measures and provides suggested default values.

The HCM provides two bicycle performance measures for urban street segments and facilities: average travel speed (reflecting intersection delays) and a bicycle LOS (BLOS) score (reflecting bicyclist comfort with the bicycling environment). Exhibit 3-2 lists the data required for these measures and provides suggested default values.

- **NCHRP Report 825: Planning and Preliminary Engineering Applications Guide to the Highway Capacity Manual** (Dowling et al. 2016). This guide will help designers apply the methodologies of the HCM 6th Ed. “to common project planning and preliminary engineering analyses (including scenario planning and system performance monitoring). It shows how the HCM can interact with travel demand forecasting, mobile source emission, and

Exhibit 3-1. Required data for urban street pedestrian analysis.

Input Data (units)	For SPC	For SPD	For PLOS	Default Value
Sidewalk width (ft.)	•	•	•	12 (CBD), 5 (other)
Effective sidewalk width (ft.)	•	•		8.5 (CBD), 3.5 (other)
Bi-directional pedestrian volume (ped./h.)	•	•		Must be provided
Free-flow pedestrian speed (ft./sec.)	•	•	•	4.4
Segment length (ft.) *		•	•	Must be provided
Signalized intersection delay walking along street (sec.) *		•	•	See Section O5 or use 12 (CBD), 30 (suburban)
Signalized intersection delay crossing street (sec.) *			•	See Section O5 or use 12 (CBD), 50 (suburban)
Outside lane width (ft.) *			•	12
Bicycle lane width (ft.)			•	0
Shoulder/parking lane width (ft.)			•	1.5 (curb and gutter only) 8 (parking lane provided)
Percentage of segment with occupied on-street parking (decimal)			•	0.00 (no parking lane) 0.50 (parking lane provided)
Street trees or other barriers (yes/no) **			•	No
Landscape buffer width (ft.)			•	0 (CBD), 6 (other)
Curb presence (yes/no)			•	Yes
Median type (divided/undivided)			•	Undivided
Number of travel lanes *			•	Must be provided
Directional vehicle volume (veh./h.) *			•	Must be provided
Vehicle running speed (mph) *			•	See Section K6 or use the posted speed
Intersection PLOS score (unitless)			•	Calculated, see Section O5
Average distance to nearest signal (ft.)			•	One-third the segment length

Section numbers refer to content in *NCHRP Report 825*.

See HCM 6th Ed., Chapter 18, for definitions of the required input data.

SPC = space; SPD = speed; PLOS = pedestrian LOS; CBD = central business district.

* Input data used by or calculation output from the HCM urban street motorized vehicle LOS method.

** Street trees, bollards, or other similar vertical barriers 3 ft. or more tall, or continuous barrier at least 3 ft. tall.

Source: From Exhibit 98 in *NCHRP Report 825* (Dowling et al. 2016)

Exhibit 3-2. Required data for urban street bicycle analysis.

Input Data (units)	For SPD	For BLOS	Default Value
Bicycle running speed (mph)	•		12
Signalized intersection delay (s)	•	•	See Section O5 or use 10 (CBD), 22 (suburban)
Segment length (ft.) *	•	•	Must be provided
Bicycle lane width (ft.) **		•	5 (if provided)
Outside lane width (ft.) **		•	12
Shoulder/parking lane width (ft.) **		•	0 (curb and gutter only) 8 (parking lane provided)
Percentage of segment with occupied on-street parking (%) **		•	0 (no parking lane) 50 (parking lane provided)
Pavement condition rating (1–5)		•	3.5 (good)
Curb presence (yes/no) **		•	Yes
Median type (divided/undivided) **		•	Undivided
Number of travel lanes *		•	Must be provided
Directional vehicle volume (veh./h.) *		•	Must be provided
Vehicle running speed (mph) *		•	See Section K6 or use the posted speed
Percentage heavy vehicles (%) *		•	3%
Access points on the right side (points/mi.)		•	17 (urban arterial), 10.5 (suburban arterial), 30.5 (urban collector), 24 (suburban collector)
Intersection BLOS score (unitless)		•	Calculated, see Section O5

Section numbers refer to content in *NCHRP Report 825*.

See HCM 6th Ed., Chapter 18, for definitions of the required input data.

SPD = speed; BLOS = bicycle LOS; CBD = central business district.

* Input data used by or calculation output from the HCM urban street motorized vehicle LOS method.

** Input data used by the HCM urban street PLOS method.

Source: From Exhibit 101 in *NCHRP Report 825* (Dowling et al. 2016)

simulation models and its application to multimodal analyses and oversaturated conditions. In addition to providing a cost-effective and reliable approach to analysis, the guide provides a practical introduction to the detailed methodologies of the HCM.”

- **AASHTO’s *Highway Safety Manual* (HSM) (AASHTO 2010).** The purpose of the HSM is to provide the best information and proven analysis tools for crash frequency prediction. The manual focuses on the “increased application of analytical tools for assessing the safety impacts of transportation project and program decisions.” The HSM can be used in the project design process to (FHWA 2014e):

- Identify factors contributing to crashes and associated potential countermeasures to address these issues.
- Evaluate the crash reduction benefits of implemented treatments [. . .].
- Calculate the effect of various design alternatives on crash frequency and severity.

The HSM also includes an Interactive Highway Safety Design Model (IHSDM), a suite of software analysis tools for evaluating safety and operational effects of geometric design decisions (FHWA 2003). It provides estimates of a highway design’s expected safety and operational performance and checks existing or proposed highway designs against relevant design policy values.

Chapter 12 in the HSM provides a structured methodology for estimating the predicted and/or expected average crash frequency, crash severity, and collision types for urban and suburban arterial facilities. Crashes involving all vehicle types, bicycles, and pedestrians are included, except for crashes between bicycles and pedestrians. The methodology is applicable to existing sites, design alternatives to existing sites, new sites, and alternative traffic volume projections. Chapter 12 can be applied to all arterials located inside urban areas that have a population

greater than 5,000. The chapter includes arterials other than freeways without full access control with two- or four-lane undivided facilities, four-lane divided and three- and five-lane roads with center TWLTLs in urban and suburban areas. Chapter 12 also includes three- and four-leg intersections with minor-road stop control or traffic signal control on all of the roadway cross sections to which the chapter applies.

- **NCHRP Report 839: A Performance-Based Highway Geometric Design Process** (Neuman et al. 2017). The research on which this report is based assesses the existing geometric design process and presents suggested changes to ensure that recent advances in knowledge and emerging issues are incorporated in the design process. The report proposes that the end goal of all geometric design needs to be measured in the metrics of transportation performance, including mobility, accessibility, safety, maintenance and operations, and state-of-good-repair. Every phase, methodology or model developed and applied to conducting the highway design and to establishing the highway design criteria should be objectively related to one or more measures of transportation performance.

The revised geometric design process recommended by *NCHRP Report 839* provides guidelines based on the project type and the problem or need being addressed. As noted in the report summary, “The geometric design criteria for any given project is recommended to be based on the context of the project location, and not limited to the facility type. This revised highway design process is intended for further development to become fully implementable” (Neuman et al. 2017).

The report further acknowledges that the geometric design process, historically focused solely on motorized vehicles, must evolve to more directly and routinely address the needs of all potential users of a facility or corridor. Process and cultural change within the road design community are needed. Prioritizing the amount and manner of transportation service afforded general-purpose traffic, transit, truck and freight traffic, bicyclists and pedestrians involves inherent conflicts and choices. A design process that directs the resolution of such conflicts can establish a balance of choices among all needs.

NCHRP Report 839 suggests more refined context definitions to identify corridors and conditions in which, for example, pedestrian needs should take precedence over motorized vehicles (e.g., to ensure that pedestrian facilities comply with ADA requirements). The presumptive need to design cross sections, intersections and vertical alignment recognizing the presence of bicycles is similarly desirable.

- **TCRP Report 165: Transit Capacity and Quality of Service Manual, 3d Ed. (TCQSM 3d Ed.)** (Kittelson and Associates, Inc., et al. 2013). The TCQSM 3d Ed. focuses on the evaluation of transit facilities, whereas the HCM considers the effects of transit presence along urban streets within its multimodal analysis framework. As a reference document, the TCQSM 3d Ed. functions as a companion to the HCM that provides current research-based guidance on transit capacity and QOS issues and the factors influencing both.

The manual contains background, statistics and graphics on the various types of public transportation, and it provides a framework for measuring transit availability, comfort, and convenience from the passenger and transit provider points of view. The manual contains quantitative techniques for calculating the capacity and other operational characteristics of bus, rail, demand-responsive, and ferry transit services, as well as transit stops, stations, and terminals. Example calculations are included. The TCQSM and the accompanying CD-ROM are intended for use by a range of practitioners, including transit planners, transportation planners, traffic engineers, transit operations personnel, design engineers, management personnel, teachers, and university students.

- **NCHRP Report 785: Performance-Based Analysis of Geometric Design of Highways and Streets** (Ray et al. 2014). This report presents an approach for understanding the desired outcomes of a project, selecting performance measures that align with those outcomes, evaluating the impact of alternative geometric design decisions on those performance measures, and arriving at solutions that achieve the overall desired project outcomes. For both new

construction and reconstruction of highways and streets, stakeholders and decision makers increasingly want reasonable measures of the effect of geometric design decisions on the facility's performance for all of its users. The report includes information that helps a designer develop the foundation for performance-based analysis to inform geometric design decisions, followed by applications guidance to incorporate performance-based analysis into project development and geometric design decisions. The report correctly notes that the expected performance of the facility is only one of the factors that must be considered in designing a highway or street, and a better understanding of the expected performance should result in better decisions during the design process.

- ***Applying Performance Based Practical Design Methods to Complete Streets—A Primer on Employing Performance-Based Practical Design and Transportation Systems Management and Operations to Enhance the Design of Complete Streets (FHWA 2016b)***. This primer addresses performance-based “practical design” (PBPD) approaches for roadways being designed to serve all users, recognizing that urban and suburban streets must serve many types of users and trips in right-of-way that is often constrained. It discusses use of design principles that seek to better share the limited street right-of-way among multiple users while enhancing the livability of the street for adjacent residents. The primer describes how PBPD modifies the traditional “top-down, standards-first” approach to a “design up” approach in which designers and decision makers exercise engineering judgment to build up the roadway and operational improvements from existing conditions to meet both project and system objectives.

The primer also describes how PBPD uses appropriate analysis tools to evaluate the performance impacts of planning and design decisions in relation to the cost of providing various geometric elements and operational features. The primer notes that for lower-volume and lower-speed streets (defined as under 20,000 average annual daily traffic [AADT] and under 35 mph), many of the design trade-offs (e.g., narrow lanes, reduced lanes, adding bike lanes) are easy to make, requiring little formal trade-off analysis. The larger challenge exists with retrofitting for improved pedestrian, bicycle and transit accessibility on a higher volume or higher speed street where a more formal trade-off analysis using the PBPD process should be used.

- ***Evaluating Complete Streets Projects: A Guide for Practitioners (AARP and the National Complete Streets Coalition 2015)***. This guidebook provides a range of measures and metrics for project evaluation. The guidebook notes common project goals, which include:

providing access to destinations, supporting the local economy, ensuring environmental quality, providing vital public places and improving safety for all travelers. Additionally, many communities focus on the goals of improving public health and addressing equity, both of which have measures cut across other goals.

For each goal, the guidebook provides potential “complete streets” measures and ways to quantify each measure that can be used before and after completion of a specific project. The following measures and metrics are addressed for project level evaluation (AARP and the National Complete Streets Coalition 2015):

- Access;
 - Economy;
 - Environment;
 - Place;
 - Safety;
 - Equity; and
 - Public health.
- ***Guide to Sustainable Transportation Performance Measures (U.S. EPA 2011)***. This guidebook identifies ten performance measures that can readily be developed and applied in transportation decision making. For each measure, the EPA guide presents possible

metrics, summarizes the relevant analytical methods and data sources, and illustrates the use of each measure by one or more transportation agencies. The ten profiled measures are:

1. Transit accessibility,
2. Bicycle and pedestrian mode share,
3. VMT per capita,
4. Carbon intensity,
5. Mixed land uses,
6. Transportation affordability,
7. Distribution of benefits by income group,
8. Land consumption,
9. Bicycle and pedestrian activity and safety, and
10. Bicycle and pedestrian LOS.

3.2.4 Selecting Performance Measure, LOS and QOS Tools

The documents reviewed in the preceding section and those listed in Exhibit 3-3 provide tools that can assist the designer in assessing performance, LOS and QOS for the full range of users and modes in the design of road and street facilities in low- and intermediate-speed ranges. Although these publications differ widely in the scale and complexity of their approaches, the resource documents listed in Exhibit 3-3 also are potentially valuable resources that can support the design practitioner in evaluating and making design choices for multimodal design. The methods and tools addressed range from data-intensive quantitative analysis to low-data qualitative approaches and tools that combine quantitative and qualitative methods.

3.3 Design Volumes and Design Years

Transportation demands, including volume of users, composition of users and patterns of users, are all important design controls. Conventional geometric design processes have typically focused only on current and future projections of vehicle and truck demand. Where projects will serve non-motorized users in addition to vehicular traffic, however, it is important to obtain and understand similar demand data and patterns for transit vehicles and riders, pedestrians and bicyclists to perform multimodal design effectively. The designer must have a good understanding of both existing and anticipated demands to size, locate and integrate transit, bicycle and pedestrian facilities into the overall project design. Community planning and corridor goals, the selected design year, and other identified project performance measures also are key determinants of how the design will achieve the project's purpose and serve all users.

3.3.1 Selecting a Project Design Year

Normally, project designs accommodate travel demands likely to occur within the life of the facility under reasonable maintenance. This usually involves projecting future conditions for a selected planning horizon year. Projections of future demand for larger transportation projects usually are made for a range of 15 to 30 years. For large projects, agencies often will select 20 years from the expected facility completion date as the design year. Many agencies consider this a reasonable compromise between a facility's useful life, the uncertainties of long-range projections, and the consequences of inaccurate projections. For smaller, lower-cost projects, agencies will often use a planning horizon of 5 to 10 years.

Exhibit 3-3. Resources for assessing multimodal performance measures, LOS and QOS.

Resource Document	User Facilities					
	Combined (All Users)	Vehicles	Pedestrians	Bicycles	Shared- Use Path	Transit
<i>Guidebook for Developing Pedestrian and Bicycle Performance Measures</i> (FHWA 2016c)			X	X		
HCM 6th Ed. (TRB 2016b)	X	X	X	X	X	X
HSM (AASHTO 2010) *	X	X	X	X		
<i>NCHRP Report 825</i> (Dowling et al. 2016)	X	X	X	X	X	X
<i>NCHRP Report 839</i> (Neuman et al. 2017)	X	X	X	X	X	X
<i>Analysis Procedures Manual</i> (APM) (Oregon DOT 2016), Chapter 14: Multimodal Analysis	X	X	X	X	X	X
<i>Evaluating Complete Streets Projects: A Guide for Practitioners</i> (AARP and the National Complete Streets Coalition 2015)	X	X	X	X	X	X
TCQSM 3d Ed. (Kittelson and Associates, Inc., et al. 2013)						X
<i>Quality/Level of Service Handbook</i> (Florida DOT 2013)	X	X	X	X	X	X
<i>Low-Stress Bicycling and Network Connectivity</i> , MTI Report 11-19 (MTI 2012)				X		
"Multimodal Level of Service in King County: A Guide to Incorporating All Modes of Transportation into Local Jurisdictions' Roadway Performance Measurements," slide presentation (Cascade Bicycle Club 2011)	X	X	X	X	X	X
"HPE's Walkability Index: Quantifying the Pedestrian Experience" in the <i>Compendium of Technical Papers, ITE 2010 Technical Conference and Exhibit, Savannah, GA</i> (ITE 2010b)			X			
Flagstaff Pathways 2030 Regional Transportation Plan (Flagstaff MPO 2009), Level of Service Guidelines for Pedestrian, Bicycle and Transit Facilities			X	X		X
<i>Bicycle Environmental Quality Index (BEQI): Draft Report</i> (SFDPH 2009), Pedestrian and Bicycle Environmental Quality Indices			X	X		
Multimodal LOS Standards for Signalized Intersections (City of Charlotte, NC 2007a)	X	X	X	X		X
<i>Evaluation of Safety, Design, and Operation of Shared-Use Paths - Final Report</i> , FHWA-HRT-05-137 (FHWA 2006a)			X	X	X	
<i>Multimodal Transportation Level of Service Manual</i> (City of Fort Collins, CO 1997)	X	X	X	X		X
<i>Multimodal Level of Service Toolkit</i> (Fehr and Peers n.d.)	X	X	X	X		X
Bicycle Level of Service: Applied Model (Sprinkle Consulting, Inc. 2007a)				X		
Pedestrian Level-of-Service Model (Sprinkle Consulting, Inc. 2007b)			X			

* With 2014 supplements

3.3.2 Projecting Future Multimodal Demand

Forecasts of future *user demand* should reflect community and regional plans, changes in project context over the analysis period, and the project's purpose and need. Based on these considerations, a future conditions projection represents a technical analysis and policy consensus on the type and developed intensity of land use, future local and regional economic activity, presence of transit service, changes in transit service, the anticipated presence and needs of pedestrians and bicyclists, and other possible factors.

Forecasts of future *user activity levels* should include estimates of pedestrian and bicycle activity as well as transit vehicles and other motorized vehicles. Particular care must be taken when forecasting pedestrian and bicycle volumes. Latent potential demand above observed pedestrian and bicycle volumes in the project area may exist if no adequate facilities exist for those users, if existing facilities are substandard in some way, or if they do not provide complete connectivity to existing or planned destinations. It is also important to evaluate future land use context and development, including any potential attractors such as new transit service lines or stops, schools, parks, office and retail uses that may be located near existing or planned residential development.

In many communities, computer-based transportation demand models, typically developed at the regional level, are used as the basis for vehicle traffic projections. Typically, the computer model is calibrated to emulate existing and future transportation demands based on current and future projections of land use growth (population, economy and employment), planned transportation investments and estimated percent of non-vehicular travel (e.g., transit trips and, in some regions, bicycle trips).

If transportation demand models are not available or not used to project future traffic, many agencies will apply an average annual growth percentage—often in the range of 1 to 2 percent—to estimate future design year project volumes. When applied over a 20-year or 30-year period, the annual growth percentage will result in significant traffic growth. For example, a 2 percent traffic growth rate applied over 35 years will approximately double the amount of traffic compared to the traffic in place today. The typical process for forecasting user volumes assumes that traffic will increase over time, at many locations; however, buildout or near buildout of land use will have occurred already, and user volumes may remain relatively constant or even decline over time.

Individual projects should be assessed on a case-by-case basis to analyze how standard traffic growth factors (land use trip generation, ambient growth) may support or conflict with the corridor and community plans. Future analysis should typically begin with the vision for the future function of the road, including the roadside and land use context, so that design treatments can support and complement these goals. Some communities intentionally constrain roadways to inhibit growth when their overall vision for the roadway is considered more important than the roadway's vehicle traffic-carrying capacity.

Ideally, in multimodal environments, community planners and roadway designers work together to determine the appropriate estimates of future modal activity levels to use as a foundation for the design process. For the typical project undertaken within a community (e.g., an intersection or corridor improvement project), the user demand forecast is based on existing conditions.

3.3.3 Pedestrian Demands

Pedestrian counts are completed to determine pedestrian flows, patterns and peak hours. The pedestrian counts should include sidewalk demands, crossing demands, and storage demands at corners, traffic islands and medians (i.e., total number of pedestrians waiting to cross the street).

Seasonal adjustments to the counts may be needed to ensure the count data accurately represents the average annual conditions. Finally, future design year conditions are estimated by adding to or subtracting from the existing traffic volumes to account for any network changes, future projects and future changes in localized development and context.

In addition to pedestrian counts, the project area should be evaluated to determine if latent potential demand for pedestrian accommodation exists because of an uncomfortable existing walking environment, missing links in the pedestrian network or expected changes in development patterns. The likelihood of latent demand can be assessed by looking at surrounding land uses and their propensity to generate pedestrian activity. Designers also can look for conditions like pathways worn along the roadside to determine if pedestrian connectivity is underserved.

It may be important to complete pedestrian counts for other times of the day (beyond the typical morning and evening peak hours) and/or on weekends, depending on the project area. For example, observing pedestrian flows during morning and mid-afternoon periods will be important for a project area that is heavily influenced by a school. Public assembly facilities and transit stops or stations also merit special consideration because they can produce high volumes of pedestrians over short durations.

To determine the appropriate locations for pedestrian counts (including project-area intersections), it is important to review current pedestrian routes between activity centers. Informal paths or crossing locations may warrant supplemental pedestrian observations during project planning.

3.3.4 Bicycle Demands

Bicycle demands should be counted during peak hours concurrent with vehicle intersection turning movement counts. As with pedestrian activity, the designer should evaluate the project area to determine if potential latent demand exists for bicycle accommodation. Additional consideration of bicycle demands during other periods of the day and/or on weekends may warrant supplemental counts. Methods for forecasting bicycle demand are still evolving through national transportation research. Common practices to gauge future demands currently include sampling demand at similar settings or facilities and evaluating surrounding land uses for their propensity to generate bicycle activity.

3.3.5 Motorized-Vehicle Demands

Daily traffic, peak-hour traffic, and traffic patterns of motorized vehicles are needed as input to the design of street and roadway facilities. The following vehicle measure projections are developed for a typical roadway design project:

- **AADT:** The total yearly volume of automobiles and trucks divided by the number of days in the year;
- **Average daily traffic (ADT):** The calculation of average traffic volumes in a time period greater than one day and less than one year;
- **Peak-hour traffic (PH):** The highest number of vehicles passing over a section of roadway during 60 consecutive minutes, with T(PH) used to indicate the PH for truck traffic only;
- **Peak-hour factor (PHF):** A ratio of the total volume occurring during the peak hour to the maximum rate of flow during a given time period within the peak hour (typically is 15 minutes);
- **Design hourly volume (DHV):** The 1-hour volume in the design year selected for determining the geometric requirements of the roadway design (often the typical worst-case weekday morning or evening peak hour or the 30th-highest hour of the year); and
- **K-factor (K):** The percent of daily traffic that occurs during the peak hour.

Planning and design of transportation projects will generally need turning movement counts (TMCs) at intersections, including heavy vehicle movements and automatic traffic recorder (ATR) vehicle classification counts along roadways. These counts can be used to provide estimates of the values for the listed projections. Where pedestrian and bicycle activity are present, the counts should include them, and all counts should be performed in fair weather.

The DHV (or the daily peak hours) influence design elements, such as the desired number of travel lanes, lane and shoulder width, and intersection layouts. The DHV also may influence the LOS provided and the accommodation appropriate for pedestrians and bicyclists.

The selected DHV has a significant impact on the characteristics of a project. Designers should ensure that the selected DHV effectively matches the facility to the traffic volumes it will carry on a regular basis so that the project is not “over-designed.” For example, accommodating a high volume that is expected to occur infrequently may result in a costly project that has significant adverse impacts. Likewise, accommodating a lower design volume that frequently is exceeded may result in significant congestion and not meet the LOS expectations for various users.

Large or heavy vehicles, such as trucks and buses, have different operating characteristics from passenger cars and bicycles, and these characteristics can affect traffic operations. In planning and design, the number of trucks and buses expected to use a facility needs to be estimated for both daily and peak-hour conditions. For highway capacity purposes, *heavy vehicles* typically are defined as all buses, single-unit trucks, and truck combinations other than light delivery trucks.

3.4 Recommended Minimum Multimodal Accommodation

Agencies and designers often ask, “What is a reasonable minimum accommodation for all users?” To serve motorized vehicles on a low-volume and low-speed two-way street, the minimum is one travel lane in each direction with a minimum lane width of 9 to 10 ft. As volumes and speeds increase, the number and width of lanes also increase as needed for vehicle mobility and safety purposes. In the case of pedestrians, the minimum accommodation can range from (1) no facilities in rural contexts with no (or rare) demand, to (2) traveled way shoulders in rural settings with infrequent levels of pedestrian activity, and (3) paved sidewalks of 5 ft. and wider in rural town, suburban, urban and urban core contexts. In the case of bicyclists, the minimum accommodation on low-volume, low-speed roadways may be shared use of vehicle lanes. As volumes increase in suburban and urban contexts, the minimum accommodation may be determined to be striped bicycle lanes, separated bicycle tracks and even off-street paths located in the roadway border area. Transit accommodation also can vary widely based on the type and frequency of transit service and ridership.

For many years, the HCM has assisted designers in determining the minimum traveled way design to provide a desired LOS for motorized vehicles. Many factors, including functional classification, design volumes, design vehicles, design speed and other criteria, have led designers to develop acceptable project designs meeting desired performance measures using geometric design guidance such as the AASHTO Green Book and supporting publications. During this same period, however, generally little definitive guidance has been available on minimum accommodation for non-motorized or transit modes that may be legally using the right-of-way. Many past project designs either have not provided reasonable accommodation for pedestrian, bicycle and transit users or have provided such accommodation as an afterthought, resulting in poor service and quality levels.

Considerable discussion, along with some debate, has been devoted to what type and level of accommodation constitutes a “minimum” reasonable accommodation for pedestrians, bicyclists

and transit access in the street and roadway system. As pedestrian and bicycle travel have increased over time (along with related crash and fatality rates), more state, local and federal agencies have placed new or expanded focus on providing more and better facilities for these users in the right-of-way, even though their numbers are small compared to motorized user volumes. This multimodal focus also reflects increased efforts to create more vibrant and livable communities and neighborhoods that support a healthier lifestyle and support a community's economic goals. With those goals and benefits in mind, the minimum accommodation shown in Exhibit 3-4 is suggested for low- and intermediate-speed streets and roads where non-motorized users are allowed to use the right-of-way by law.

The needs of all legal users of the right-of-way, including pedestrians, bicyclists and transit users, should be considered in the design of a roadway project unless a user mode is specifically prohibited on that facility by law. FHWA provides comprehensive guidance for the provision of reasonable facilities to accommodate these transportation system users without the application of detailed multimodal analysis in the Pedestrian Safety Guide and Countermeasure Selection System and the Bicycle Safety Guide and Countermeasure Selection System on its *PedBikeSafe* website (FHWA n.d.d). Another source of information is the PROWAG (U.S. Access Board 2011).

Constraints and possible exceptions to these minimum recommended accommodations will always exist because of several possible factors that could affect a given project; in general, however, the ability for all legal users to access and conveniently use a roadway right-of-way in a safe and reasonable manner should be provided regardless of the level of their activity. Pedestrians, bicyclists and transit users almost always will constitute lower volumes than motorized vehicles except in some urban core contexts, but their opportunity to use the roadway right-of-way is no less important than that of drivers.

Exhibit 3-4. Minimum recommended low- and intermediate-speed roadway user accommodation by context zone.

Context	User			
	Motorized vehicles	Pedestrians	Bicycles	Transit
Rural	Minimum number of travel lanes determined by functional classification, transportation plans and selected performance measures, balanced with other modal needs within the right-of-way.	Minimum 4-ft. paved or stabilized shoulders on both sides of road unless volumes and speeds are low.* Separate paved sidewalks/paths not normally required unless nearby pedestrian generators exist.	Determined by existing and planned bicycle usage. May range from no facilities, to use of roadway shoulder (min. 4 ft.), to on-street striped bicycle lanes, to separated cycle tracks, to roadside bicycle or shared-use paths. State, regional and local bicycle and transportation plans should be consulted.	Traveled way transit facilities determined by selected performance measures. Minimum 5-ft. paved accessible sidewalks or path from nearby pedestrian generators to transit stops. Additional transit stop facilities as needed for demand.
Rural Town		Minimum 5-ft. paved accessible sidewalks or pathways along both sides of roadway unless volumes and speeds are low.*		
Suburban		Minimum 5-ft. paved accessible sidewalks or path along both sides of roadway unless volumes and speeds are low.*		
Urban		Minimum 5-ft. paved accessible sidewalks or path along both sides of roadway.		
Urban Core		Minimum 5-ft. paved accessible sidewalks or path along both sides of roadway.		

* ADT = 2,000 vehicles per day or less, 85th percentile speeds 30 mph or lower

Exceptions to meeting the minimum accommodations follow the FHWA guidance on accommodating bicycle and pedestrian travel and identified best practices for providing multimodal accommodation. Accommodation is not necessary in the following cases:

- **Prohibited use.** This exception involves corridors where specific users are prohibited by law (e.g., Interstate highways/freeways, expressways or pedestrian malls).
- **No observed or planned need.** This exception involves a documented absence, or extremely infrequent expectation, of current and future need for a particular mode.
- **Cost.** This exception occurs when the cost to provide accommodation for one or more modes is excessively disproportionate to the need or probable use. Determining a percentage cost to define “excessive” is difficult, as the context for many projects requires different portions of the overall project budget to be spent on the modes and users expected; additionally, the costs often may be difficult to quantify. A percentage cap may be appropriate in unusual circumstances, such as where natural features (e.g., steep hillsides, shorelines) or environmental constraints make it very costly or even impossible to accommodate all modes. If an identified percentage increase cap exists, it should normally be used in an advisory sense rather than absolute sense.
- **Alternate accommodation.** This exception occurs when a reasonable and equivalent accommodation project along the same route or corridor is already programmed to provide reasonable replacement facilities for those exempted from the project being designed.

3.5 Relationships between Geometric Design and Performance of All Users

NCHRP Report 785 (Ray et al. 2014) provides performance-based guidance in four key areas:

- Selecting the desired outcomes of a project;
- Selecting performance measures that help to achieve those outcomes;
- Evaluating how various alternative geometric design decisions may impact those measures; and
- Selecting preferred design solutions that help to achieve the overall desired project outcomes.

The first part of *NCHRP Report 785* presents the body of knowledge that forms the foundation for performance-based analysis to inform geometric design decisions, and the second part provides applications guidance to incorporate performance-based analysis into project development and geometric design decisions.

Geometric design decisions for roadways and streets act individually and together to impact project performance in ways that may or may not be consistent with broader community goals not related to vehicle traffic flow. *NCHRP Report 785* guides the user in conducting performance-based analysis and can assist geometric designers in better understanding the most critical transportation performance areas and how they relate to geometric design elements.

NCHRP Report 785 identifies and defines five key transportation performance categories. Although the designer should consult the full report for specific guidance on how to incorporate performance-based analysis into the design of their projects, the following points highlight key parts of the report’s discussion of relationship between key categories of roadway facility performance and individual geometric design elements:

- **Access and accessibility.** The report defines *accessibility* as “the ability to approach a desired destination or potential opportunity for activity” using roads and streets, including the sidewalks and/or bicycle lanes provided within those rights-of-way. It notes that these performance measures have not traditionally been considered during geometric design stages of

project development, and that they “tend to require performance prediction tools that are typically not used by designers.” The report uses these measures to quantify accessibility: driveway density, transit stop spacing, and presence of pedestrian and/or bicycle facilities.

- **Mobility.** *NCHRP Report 785* defines *mobility* as “the ability to move various users efficiently from one place to another using roadways and streets” and identifies performance measures for mobility that are sensitive to geometric design, including “speed and measures that involve speed (e.g., delay, travel time).” Significantly, the report notes that “these measures can be equally applied to any travel mode; however, non-motorized movement performance may be more meaningfully quantified using measures of accessibility and quality of service.”
- **QOS.** Defining QOS as “the perceived quality of travel by a road user,” the report notes that QOS is used in the HCM “to assess multimodal level of service (MMLOS) for motorists, pedestrians, bicyclists, and transit users.” Measures of quality include “average travel speed, control delay, density, percent time-spent-following, driveway density, separation between motorized and non-motorized modes, amount of space provided for pedestrians and bicyclists, frequency of transit service, transit service amenities, and frequency of opportunities for pedestrians to cross a street.” QOS also may include “the perceived quality of travel by design vehicle users such as truck or bus drivers,” and “users’ perceptions of safety.”
- **Reliability.** Defined as “the consistency of performance over a series of time periods (e.g., hour-to-hour, day-to-day, year-to-year),” transportation service reliability “is commonly linked to travel-time variability, but the basic concept applies to any other travel-time-based metric (e.g., average speed, delay).” The report also notes that geometric design may affect a roadway’s ability “to ‘absorb’ random, additional traffic demand as well as capacity reductions due to incidents (e.g., crashes, vehicle breakdowns), weather, and maintenance operations, among others. Reliability also is indirectly related to geometry inasmuch as the geometry affects the frequency and severity of random events that impact travel time (e.g., crashes).”
- **Safety.** *NCHRP Report 785* defines *safety* as “the expected frequency and severity of crashes occurring on highways and streets,” adding that “[e]xpected crash frequencies are often disaggregated by level of crash severity and crash type, including whether or not a crash involves a non-motorized user or a specific vehicle type (e.g., heavy vehicle, transit vehicle, motorcycle). Measures that combine crash frequencies and severities into a common unit (e.g., crash cost, equivalent property damage only, relative severity index) are sometimes used when comparing design alternatives.”

3.5.1 Relationships Between Geometric Design Elements and Performance Categories

The design guidance in *NCHRP Report 785* is based on research findings from several publications and documents, including the HSM, HCM, and TCQSM 2d ed.; FHWA’s *Speed Concepts: Informational Guide* (FHWA 2009c); the *Interactive Highway Safety Design Model* (IHSDM) (FHWA 2003); draft HSM chapters for freeways and interchanges developed in the contractor’s final report for NCHRP Project 17-45, “Safety Prediction Methodology and Analysis Tool for Freeways and Interchanges” (TTI and CH2M-Hill 2012); and several additional tools that address relationships between geometric design and performance.

The information presented in *NCHRP Report 785* focuses on what are considered to be high-priority, well-established and direct relationships between geometric design decisions and performance. It stresses that practitioners should also be aware of the broader range of expected relationships, because limitations in data, analysis techniques, and other similar challenges suggest that likely relationships exist that have not yet been clearly defined, quantified and documented.

The report also provides some information on “expected” or “likely” relationships between performance and geometric elements that, as of its publication, had not yet been addressed in

published research findings. Exhibits 3-5 and 3-6 address expected relationships for roadway segments and intersections. Both tables include information on pedestrian and bicycle design facilities and other design elements that potentially affect the performance outcomes of those modes (e.g., roadside design features, bridge cross section, travel lane widths, median provisions, traffic islands and shoulder type/width).

NCHRP Report 785 develops and uses three possible notations to classify each geometric characteristic or design decision and performance category combination as either “expected direct effect,” “expected indirect effect,” or “no expected effect”: The notations are defined as follows:

Exhibit 3-5. Segments: expected geometric elements and performance relationships.

Segment Geometric Elements/Characteristics	Accessibility	Mobility	Quality of Service	Reliability	Safety
Access points and density	● ⁺	● ⁺	● ⁺	□ [◇]	● ⁺
Design speed and target speed	—	□ [◇]	□ [◇]	□ [◇]	□ ⁺
Horizontal alignment	—	● [◇]	● [◇]	□ [◇]	● ⁺
Number of travel lanes	● ⁺	● ⁺	● ⁺	□ ⁺	● ⁺
Sidewalk and pedestrian facilities (including ADA)	●	● ⁺	● ⁺	□ ^x	● ^x
Bicycle accommodation features	●	● ⁺	● ⁺	□ ^x	● ^x
Median provisions	● [◇]	● ⁺	● ⁺	□ [◇]	● ⁺
Travel lane width(s)	● [◇]	● ⁺	● ⁺	□ ⁺	● ⁺
Auxiliary lane width(s)	● ^x	● ^x	● ^x	□ ^x	● ^x
Type and location of auxiliary lanes	● [◇]	● ⁺	● ⁺	□ [◇]	● ⁺
Shoulder width(s) and composition	● [◇]	● ⁺	● ⁺	□ ⁺	● ⁺
Shoulder type(s)	● [◇]	● ^x	● ^x	□ [◇]	● ⁺
Lane & shoulder cross slopes	—	—	—	□ ^x	● ^x
Superelevation	—	● ^x	● ^x	□ [◇]	● ⁺
Roadside design features	● ^x	● ^x	● ^x	□ ^x	● ⁺
Roadside barriers	● [◇]	● ⁺	● ⁺	□ [◇]	● ⁺
Minimum horizontal clearances	● [◇]	● ⁺	● ⁺	□ [◇]	● ⁺
Minimum sight distance	● ^x	● ^x	● ^x	□ ^x	● ^x
Maximum grade(s)	□ [◇]	□ ⁺	□ ⁺	□ [◇]	□ ⁺
Minimum vertical clearances	● [◇]	□ ^x	□ ^x	□ ^x	□ ^x
Vertical alignment(s)	—	● ⁺	● ⁺	□ ⁺	● ⁺
Bridge cross section	● [◇]	● ⁺	● ⁺	□ ⁺	● ⁺
Bridge length/termini	—	—	—	□ [◇]	● ⁺
Rumble strips	● [◇]	—	—	□ ^x	● ⁺

● = expected direct effect

□ = expected indirect effect

— = expected not to have an effect

* = relationship can be directly estimated by existing performance prediction tools

◇ = relationship can be indirectly estimated using more than one existing tool

x = relationship cannot be estimated by existing tools

Source: Exhibit 4-3 in *NCHRP Report 785* (Ray et al. 2014)

Exhibit 3-6. Intersections: expected geometric elements and performance relationships.

Intersection Geometric Elements/Characteristics	Accessibility	Mobility	Quality of Service	Reliability	Safety
Intersection form, control type, and features	●◇	●*	●*	□ ^x	●*
Number and types of lanes	●◇	●*	●*	□ ^x	●*
Sidewalk and pedestrian facilities (including ADA)	●*	●*	●*	□ ^x	● ^x
Bicycle accommodation facilities	●*	●*	●*	□ ^x	● ^x
Design vehicle accommodations	□ ^x	□ ^x	□ ^x	□ ^x	□ ^x
Traffic islands	● ^x	● ^x	● ^x	□ ^x	● ^x
Lane widths	● ^x	● ^x	● ^x	□ ^x	● ^x
Auxiliary lane terminals and transitions	●◇	●*	●*	□ ^x	● ^x
Shoulder width and composition	● ^x	● ^x	● ^x	□ ^x	● ^x
Horizontal alignment of approaches	● ^x	● ^x	● ^x	□ ^x	●*
Vertical alignment of approaches	●◇	●*	●*	□ ^x	●*
Pavement cross slope and superelevation	—	—	—	□ ^x	● ^x
Intersection sight distance	● ^x	● ^x	● ^x	□ ^x	● ^x
Median opening configuration	●◇	●◇	●◇	□ ^x	● ^x
Curve tapers and radii	● ^x	● ^x	● ^x	□ ^x	● ^x

● = expected direct effect
 □ = expected indirect effect
 — = expected not to have an effect
 * = relationship can be directly estimated by existing performance prediction tools
 ◇ = relationship can be indirectly estimated using more than one existing tool
 x = relationship cannot be estimated by existing tools

Source: Exhibit 4-4 in *NCHRP Report 785* (Ray et al. 2014)

- “Expected direct effects” are performance effects caused by the geometric design decisions that occur at the same time and place (e.g., a given horizontal curve radius will immediately affect expected crash frequency at the curve location);
- “Expected indirect effects” are performance effects caused by the geometric design decision but occur either later in time (e.g., providing additional auto capacity induces more auto travel) or farther removed in distance (e.g., growth-inducing effects and other effects related to changes in the pattern of land use and traffic patterns induced by the geometric choice);
- “No expected effect” indicates a geometric characteristic or design decision that is expected to have no direct or indirect impact on the aspect of performance being assessed.

Exhibits 3-5 and 3-6 also include notations that indicate whether the expected relationship has been addressed in research and is included as part of a performance prediction tool, an accepted publication, or another knowledge source.

3.5.2 Performance Categories and Performance Measures

NCHRP Report 785 presents information about design elements and decisions related to segments and intersections, and their relationship to performance measures from each of five

previously defined transportation performance categories: (1) accessibility, (2) mobility, (3) QOS, (4) reliability and (5) safety. This section summarizes, by facility type, the performance measures specific to the five performance categories.

3.5.2.1 Accessibility

Accessibility is defined as the ability to approach a desired destination or potential opportunity for activity using highways and streets (including sidewalks and/or bicycle lanes).

Exhibit 3-7 summarizes, by facility type, the performance measures specific to access and accessibility, the sensitive geometric design elements that influence those performance measures, the basic relationship between the design elements and the performance measures and potential trade-offs between the design element and the performance of other transportation elements. The exhibit also lists resources useful for evaluating the sensitivity of the geometric relationships in detail.

3.5.2.2 Mobility

Mobility is defined as the ability to move various users efficiently from one place to another using highways and streets. Exhibit 3-8 summarizes, by facility type, the performance measures specific to mobility, the sensitive geometric design elements influencing those performance measures, the basic relationship between the design element and the performance measure, and potential trade-offs between the design element and the performance of other transportation elements. The table also lists resources that can be used to evaluate the sensitivity of that geometric relationship in detail. *NCHRP Report 785* notes specifically that improving many mobility-oriented

Exhibit 3-7. Access and accessibility performance measures.

Facility Type	Performance Measure	Definition	Geometric Design Elements	Basic Relationship	Potential Performance Trade-offs	Evaluation Resources
Segment	Driveway density	Number of driveways per mile	Access points and density	Higher density of driveways associated with higher motor vehicle access	Degrades bicycle LOS, increases crash likelihood, increases average travel speed	HCM 2010 Chapters 16 and 17; HSM Part C
Urban/Suburban Segment	Transit stop spacing	Distance between transit stops along a roadway segment	Transit accommodation features	Higher frequency increases access for transit riders	Increases transit travel time and may degrade mobility for other vehicle modes	<i>TCQSM</i>
Segment	Presence of pedestrian facility	Presence of a sidewalk, multiuse path, or shoulder	Sidewalk and pedestrian facilities	Greater connectivity and continuity of pedestrian network increase access for pedestrians	Implementing pedestrian facilities in a constrained environment may require removing capacity or parking for vehicle mode	HCM 2010 Chapters 16 and 17
Segment	Presence of bicycle facility	Presence of bicycle lanes, multiuse path, or shoulder	Bicycle accommodation features	Greater connectivity and continuity of bicycle network increase access for bicyclists	Implementing bicycle facilities in a constrained environment may require removing capacity or parking for vehicle mode	HCM 2010 Chapters 16 and 17

Source: From Exhibit 4-6 in *NCHRP Report 785* (Ray et al. 2014)

Exhibit 3-8. Mobility performance measures.

Facility Type	Performance Measure	Definition	Geometric Design Elements	Basic Relationship	Potential Performance Trade-offs	Evaluation Resources
Segment	Average travel time	The mean amount of time it takes a road user to travel from one point to another point along a roadway segment	Number of travel lanes	Increased vehicle lanes decrease average travel time for autos and increases vehicle speed	Degrades quality of service for pedestrians and bicyclists Degrades mobility for pedestrians and bicyclists	HCM 2010 Chapter 10, Freeway Facilities, Chapter 14 Multilane Highways
Segment	Inferred speed	The maximum speed for which all critical design-speed-related criteria are met at a particular location	Horizontal alignment, vertical alignment, and cross section	Higher inferred speeds associated with higher free-flow speeds and higher mobility	Higher vehicle speeds are also associated with higher severity crashes	<i>FHWA Speed Concepts: Informational Guide*</i>
Two-Lane Segment	Average percent time spent following	The average percentage of total travel time that vehicles must travel in platoons [†] behind slower vehicles due to an inability to pass	Horizontal and vertical alignment, sight distance, type and location of auxiliary lanes	Increased opportunities to pass slow-moving vehicles reduces percent time spent following, providing a passing lane can reduce crashes	Increases vehicle speeds, increases potential for higher severity crashes	HSM Chapter 10; HCM 2010 Chapter 15
Freeway Segment	Freeway speed	The freeway speed downstream of an entrance ramp and before an exit ramp or another entrance ramp	Ramp spacing dimensions as defined in NCHRP Report 687 Use of downstream auxiliary lane	At relatively high exit ramp volumes, ramp spacing affects freeway speeds	Decreased freeway speeds are possible with decreased ramp spacing An auxiliary lane may improve freeway speeds	<i>NCHRP Report 687 **</i> , HCM 2010 Chapters 11, 12 and 13
Intersection	Delay	Average control delay experienced by road users at an intersection	Intersection form, control type, and features; number and types of lanes	Lower control delay for any road user improves mobility for that mode	Often trade-offs occur between delay experienced by different modes depending on the type of traffic control present	HCM 2010 Chapters 18 through 22; <i>NCHRP Report 672 ***</i>
Intersection	Volume-to-capacity (v/c) ratio	The ratio of volume present or forecasted and the available capacity at the intersection	Intersection form, control type, and features; number and types of lanes	Increased vehicle capacity associated with lower v/c ratios	Degrades quality of service for pedestrians and bicyclists Degrades mobility for pedestrians and bicyclists	HCM 2010 Chapters 18 through 22; <i>NCHRP Report 672</i>

* *FHWA Speed Concepts: Informational Guide* (Donnell et al. 2009)** *NCHRP Report 687* (Ray et al. 2011)*** *NCHRP Report 672* (Rodegerdts et al. 2010)Source: From Exhibit 4-7 in *NCHRP Report 785* (Ray et al. 2014)

performance measures for vehicles can potentially negatively affect the QOS for pedestrians, bicyclists, or transit users. The trade-off that often occurs in providing additional vehicle capacity is increased speeds of motorized vehicles. Increased speeds are associated with lower QOS (e.g., lower comfort and safety) for pedestrian, bicycle, and transit modes. Additional vehicle capacity also can come at the expense of providing pedestrian or bicycle facilities. In some cases, however, providing a bicycle lane can provide a de facto shoulder or a shoulder can serve as a de facto bicycle lane.

3.5.2.3 QOS

QOS is defined as the perceived quality of travel by a road user. In the HCM 2010, QOS is used to assess LOS simultaneously for motorists, pedestrians, bicyclists, and transit riders (i.e., MMLOS). It may also include the perceived quality of travel by users of larger vehicles such as trucks or transit vehicles. The QOS metrics summarized in Exhibit 3-9 represent a combination of recent advancements in how the transportation profession understands, evaluates and attempts to quantify quality of travel experience for different road users and fundamental considerations related to critical design vehicles that need to be served within a project. Research on multimodal QOS, especially that related to pedestrian and bicycle QOS, will likely continue to evolve as practitioners increase their focus and attention on creating (or retrofitting existing roadways to create) “complete streets” that better serve a wide range of road users.

Exhibit 3-9 summarizes, by facility type, the performance measures specific to QOS, the sensitive geometric design elements influencing those performance measures, the basic relationship between the design element and the performance measure, and potential trade-offs between the design element and the performance of other transportation elements. The table also lists resources that can be used to evaluate the sensitivity of that geometric relationship in detail.

3.5.2.4 Reliability

Research continues in the transportation profession to develop performance measures that can connect reliability to specific geometric design elements or decisions, but at publication of *NCHRP Report 785* the authors noted that no clear set of measures was yet available to use in making design decisions. The authors observed that two performance measures (variation in travel time and variation in speed) were used to understand potential reliability of a facility for the vehicle mode, and that several design considerations could be applied to roadways and streets, including trade-offs between implementing transit signal priority, bus-only lanes, and/or queue jumps for transit vehicles along an urban corridor to improve the reliability of bus service with the potential impact of degrading mobility for side street vehicle traffic. No mention is made in the report of how providing reliability may be related to elements of design for pedestrians and bicycles.

3.5.2.5 Safety

Safety is defined as the frequency and severity of crashes occurring on or expected to occur on roadways or streets. Exhibit 3-10 summarizes, by facility type, the performance measures specific to safety, the sensitive geometric design elements that influence those performance measures, the basic relationship between the design element and the performance measure, and resources or tools that can be used to evaluate the sensitivity of that geometric relationship in detail. *NCHRP Report 785* also notes other resources that may be beneficial in considering safety performance, including FHWA’s Crash Modification Factor Clearinghouse webpage (CMF Clearinghouse n.d.).

Exhibit 3-9. QOS performance measures.

Facility Type	Performance Measure	Definition	Geometric Design Elements	Basic Relationship	Potential Performance Trade-offs	Evaluation Resources
Urban/ Suburban Segment	Pedestrian LOS	A letter grade associated with the quality of travel experience for a pedestrian; based on HCM 2010 methodology	Sidewalk and pedestrian facilities, width of pedestrian lanes, buffer from vehicle traffic, driveway density, crossing frequency	Increasing width of pedestrian facility, increasing distance from vehicle traffic, decreasing driveway density, and increasing opportunities to cross a street improve pedestrian LOS	Meeting performance metrics for pedestrians may degrade travel quality for other modes – e.g., on-street parking improves pedestrian LOS and degrades BLOS	HCM 2010 Chapters 16 and 17
Urban/ Suburban Intersections	Pedestrian LOS	A letter grade associated with the quality of travel experience for a pedestrian; based on HCM 2010 methodology	Crossing distance, traffic control delay	Decreasing pedestrian crossing distance and delay to cross a street improves pedestrian LOS	Meeting performance metrics for pedestrians may degrade travel quality for other modes	HCM 2010 Chapters 16 and 17
Urban/ Suburban Segment	BLOS	A letter grade associated with the quality of travel experience for a bicyclist; based on HCM 2010 methodology	Bicycle accommodation features, physical separation from motorized vehicle traffic, access points and density, on-street parking	Increasing width of bicycle facility, decreasing driveway density, increasing separation from moving vehicle traffic, and removing on-street parking improve BLOS	Meeting performance metrics for bicyclists may degrade travel quality for other modes	HCM 2010 Chapters 16 and 17
Urban/ Suburban Intersections	BLOS	A letter grade associated with the quality of travel experience for a bicyclist; based on HCM 2010 methodology	Traffic control, delay	Decreased delay for bicyclists increases quality of travel experience	Meeting performance metrics for bicyclists may degrade travel quality for other modes	HCM 2010 Chapters 16 and 17
Urban/ Suburban Segments and Intersections	Transit LOS	A letter grade associated with the quality of travel experience for a transit rider; based on HCM 2010 methodology	Transit accommodations/facilities (presence of transit-only lane, bus pullout areas, bus merge/diverge lanes, bus queue jump lanes)	Providing bus-only lane, queue jump lanes, merge/diverge lanes decreases bus travel time and improves transit rider quality of travel	Incorporating transit-only features often comes at the expense of providing additional auto or bicycle capacity or treatment	HCM 2010 Chapters 16 and 17
Urban/ Suburban Segments and Intersections	Auto LOS	Number and duration of stops along an urban/suburban corridor	Number of travel lanes; intersection form, control type, and features	Reducing the no. of stops and duration of stops along a corridor improves auto LOS	Increased vehicle lanes and speeds degrade pedestrian and bicycle MMLOS	HCM 2010 Chapters 16 and 17
Intersections and Segments	Large- vehicle turning and off-tracking character- istics	Ability and ease with which large vehicles are able to physically move through an intersection or along a segment	Curve radii, curb radii, lane width	Generally larger curve radii, larger curb radii, and wider vehicle lanes enable easier navigation for larger vehicles	Increasing curve radii, curb radii, and lane width often degrades pedestrian and bicycle MMLOS due to the longer crossing distances	AutoTURN, Truck Turning Templates

Source: Exhibit 4-8 in NCHRP Report 785 (Ray et al. 2014)

Exhibit 3-10. Safety performance measures.

Facility Type	Performance Measure	Definition	Geometric Design Elements	Basic Relationship	Potential Performance Trade-offs	Evaluation Resources
Rural two-lane segments			Horizontal alignment shoulder width and composition, shoulder type, lane width, type and location of auxiliary lanes, rumble strips, roadside design features, lighting, two-way left-turn lane, grade	See HSM		HSM Chapter 10
Rural two-lane intersection			Intersection form, control type, and features, number and types of lanes, lighting, skew	See HSM		HSM Chapter 10
Rural multilane segments			Shoulder width and composition, shoulder type, lane width, lane and shoulder cross slopes, median provisions, lighting, two-way left-turn lane	See HSM	Some safety improvements reduce mobility	
Rural multilane intersection	Crash frequency and severity	Expected number and severity of crashes	Intersection form, control type, and features; number and types of lanes; lighting; skew	See HSM	Reduce access (e.g., reducing driveway density, or negatively affect another performance measure	HSM Chapter 11
Urban/ suburban segments			Basic cross section, access points and density, fixed object density, median provisions, on-street parking	See HSM		HSM Chapter 12
Urban/ suburban intersection			Intersection form, control type, and features; number and types of lanes; signal phasing	See HSM		HSM Chapter 12
Freeway segments			Lane width, shoulder width and composition, ramp spacing, use of auxiliary lanes, ramp entrance/exit configurations	See final report for NCHRP Project 17-45*		Final report for NCHRP Project 17-45 *; <i>NCHRP Report 687</i>
Interchange			Interchange form and features, number and types of lanes, horizontal alignment, cross section, roadside	See final report for NCHRP Project 17-45 *		

* The contractor's final report for NCHRP Project 17-45 (TTI and CH2M-Hill 2012)

Source: Exhibit 4-9 in *NCHRP Report 785* (Ray et al. 2014)

3.6 Multimodal Project Design Development Process

Numerous approaches and processes exist for developing a street or roadway project design that effectively serves all users. Each transportation agency will normally have its own design process and procedures based on factors such as project cost, funding source, type of project (e.g., new construction; reconstruction; and resurfacing, restoration and rehabilitation, often called “3R”) and other factors. Project design normally is guided by agency design manuals and standards, and may include “typical” sections or design solutions that have already been mapped to an established process.

In most situations, when local agency street or roadway projects are located on a locally owned facility and funded only by local resources, the local agency guidelines and standards govern the

design. If a locally funded project is located on a facility owned by another agency (such as a state or federal-aid facility owned by a state DOT), the design guidelines and processes of the agency that owns the facility may need to be followed. Other projects on local or state/federal facilities may be funded by a combination of local, state and federal funds, in which case a state DOT's "local program" processes, standards and guidelines may be required to be followed in the design process. Projects located on the NHS must use the Green Book (AASHTO 2011a) as the design standard; however, strict adherence to every design criterion contained in the Green Book may not always be obligatory for the low- and intermediate-speed roadways.

3.6.1 Selecting the Appropriate Design Process for the Project

This Guide identifies three credible sources, each of which outlines particular approaches to the design of multimodal projects:

- *Designing Walkable Urban Thoroughfares: A Context-Sensitive Approach* (ITE 2010a);
- The Urban Street Design Guidelines (USDG) developed by the City of Charlotte, North Carolina, and profiled on FHWA's *Context Sensitive Solutions* website (FHWA n.d.b); and
- *NCHRP Research Report 839* (Neuman et al. 2017).

All three sources have a key feature in common: they fully consider and address the needs of all current and future users throughout the project development and design process. Because certain elements of each approach may be useful to a designer, specific elements of one process may be combined with elements of others to create a multimodal design approach that is tailored to an agency's specific needs. No two projects are the same, so this Guide suggests that designers and planners carefully develop a tailored approach for each individual project.

The constants among the three sources' design approaches are:

- Identifying alternatives in the planning phase of a project;
- A focus on stakeholder identification and engagement;
- Involvement of multidisciplinary design teams; and
- A thorough evaluation of the performance of all modes using the right-of-way.

This Guide simplifies each of these approaches to allow a streamlined process; however, the designer is encouraged to reference the original source documents for additional detail as needed.

The approaches described in the ITE and City of Charlotte documents apply more qualitative information to interpret and integrate the needs of motorized vehicles with the other anticipated users, project context and community goals. These approaches are better aligned with small- and mid-sized local agency projects than with larger-scale state and federal-aid projects. *NCHRP Research Report 839* also presents a multidisciplinary team approach, but the process described is somewhat more detailed, quantitative and structured around a design project development process that is typical for larger roadway projects.

3.6.2 Designing Walkable Urban Thoroughfares: A Context Sensitive Approach

These guidelines from ITE (2010a) present a roadway design process that, for simplicity, is organized into five stages. The suggested stages are intended as an iterative process that ideally requires collaboration with the public, stakeholders and a multidisciplinary team of professionals throughout the entire design process. The guidelines in the ITE document primarily address urban streets with operating speeds at or below 35 mph and with a goal to be "walkable," but the

project team for this Guide suggests that elements of this approach can be used for the design of all low- and intermediate-speed roadway types under any context.

- **Stage 1: Review area transportation plans.** The area transportation plan normally entails development of land use and travel demand forecasts and testing of network alternatives in considering context and community objectives. Often this stage is already available and serves as a direction or resource for the roadway designer. This first stage provides the overall basis for roadway design. The transportation plan establishes guiding principles and policies for the broader community and region. It develops and evaluates the network to ensure the transportation system accommodates projected land use growth.

The plans for a project should identify performance measures for each mode of transportation at the intersection, corridor and network level and should identify how the network supports the community's key goals. The plan should identify and prioritize discrete roadway projects from which the project development process begins. If an area transportation plan has not been prepared, ideally one should be prepared as part of the roadway design process.

Area transportation plans can be in the form of regional transportation plans, comprehensive or general plans, bicycle or pedestrian plans, or focused district, area, or specific plans.

- **Stage 2: Understand community vision for context and roadway.** In this stage, the designer collaborates with the public, stakeholders and a multidisciplinary team to develop specific goals and objectives for the project. If the community in which the project is located has developed a vision and established goals and objectives, this stage entails a thorough knowledge and understanding to ensure that the project achieves that vision. This stage requires review of planning documents, transportation and circulation plans, and land use and zoning plans or codes.

Through the assembled community vision, a multidisciplinary team can determine both the existing and future context for the area served by the roadway. The future context should define the long-term transportation and overall "place-making" function of the right-of-way and roadway. If the community lacks a vision, desires a change, or requires further detail in the project area, then an opportunity exists to use a public and/or stakeholder process to answer questions that will form the basis of a vision:

- What do we want this area of the community to be?
- What do we want this portion of the community to look like?
- How do we want this project to support the desired function of the community?

Frequently, it is desirable to use a participatory process to develop concepts and alternatives, even if a vision exists. This establishes public ownership in the project and helps meet the requirements of the National Environmental Policy Act (NEPA) and other federal requirements, where applicable.

The process for working with the public and stakeholders to develop a vision is not included in the ITE report (2010a). However, resources are available to explain the process, such as FHWA's *Public Involvement Techniques for Transportation Decision-Making* (FHWA 2015b).

- **Stage 3: Identify compatible roadway types and context zones.** The tools necessary for this stage are described in Chapter 4 of the ITE report (2010a) and are addressed in this Guide. Stage 3 relies on an understanding of the existing and future land use contexts identified in Stage 2. Together, stages 2 and 3 result in the identification of opportunities, design controls and constraints that will dictate roadway design elements and possible project phasing.

The source report can help guide the roadway design team through the process of identifying the context and the alternative roadway types best suited for the identified context zone. The initial relationship between the context zone and the roadway is tentative, given the iterative nature of Stage 3, which involves comparing needs with constraints, identifying trade-offs, and establishing priorities for design performance outcomes.

Stage 3 also involves close examination of all modal requirements (e.g., transit, bicycle, pedestrian and freight needs) and establishes design controls such as design traffic volumes for all users, speed, corridor-wide operations, right-of-way constraints and other fundamental engineering controls. Specific steps in Stage 3 include:

- Determining the context zone(s) within which each segment of the roadway is located, and
- Selecting the appropriate cross section features based on the context zone(s) and purpose of the roadway.

A project may encompass more than one context zone, and context zones will likely vary along the length of a large corridor project. Longer roadways will likely need to be divided into segments with varying design parameters and elements. Existing and projected, context zones can be determined from a community or regional comprehensive plan if one is available. In the absence of such a plan, the context zones can be derived from the description of the function and configuration, the type of the properties and buildings fronting the roadway, and whether the context is predominantly residential, commercial or possibly a combination including other land use types. The purpose of the roadway, including its functional designation, also can be determined from the area plan.

Context definitions within the roadway's planning document will assist a multidisciplinary team in developing the character and general design parameters of the roadway. The roadway's functional classification establishes the role of the roadway in the transportation network. The roadway cross section and multimodal features help determine certain design controls (e.g., target speed), the physical design of the roadway and the design elements that support the activities of adjacent uses. For urban roadways in walkable communities, the combination of roadway type, functional classification and context zone drives the selection of appropriate general design parameters. The parameters are described in detail in several chapters of the source document (ITE 2010a).

- **Stage 4: Develop and test the initial roadway concept.** Understanding the balance between the regional functions and local needs of the roadway is crucial to selecting the appropriate design criteria and preparing the initial roadway design concept. Stage 4 determines whether the street cross section concept of initial width and design features is appropriate. This stage feeds back into the previous stages if the evaluation of the concept suggests the need to change the initial roadway type or modify the system design. In this stage, a multidisciplinary team uses the design parameters identified by the context zone/roadway type combination selected in Stage 3 to determine the basic elements of the roadway and roadside that affect its width, including on-street parking, bicycle facilities, number and width of travel lanes, median and general configuration of the roadside elements.

The design team then tests and validates the initial concept at the corridor and network level of performance for all modes. A successful roadway concept is one that, when viewed as part of an overall system, maintains acceptable system-wide performance for all users, even though the individual roadway intersections or segments may experience some congestion for one or more user types. Network performance should include multimodal performance measures. Chapter 3 of the source report describes the role of the roadway in the network and references network connectivity guidelines.

Evaluation of the roadway at the corridor and network level will either validate the initial concept or indicate the need to revisit the context zone/roadway type relationship or modify the design parameters. The evaluation might even indicate the need to revise regional or sub-regional land use and circulation plans.

- **Stage 5: Develop a detailed roadway design.** Once a successful initial concept has been developed and validated in Stage 4, the process leads to the final stage: developing the detailed design elements of the traveled way and roadside. Stage 5 involves using the guidance of the source report to integrate the design of the street components, context, street-side, traveled way and intersections.

This stage also is iterative, resulting in one or more cross sections for various segments of the project. Stage 5 leads into the preliminary and final engineering steps, which include:

- Identifying the available right-of-way, desired right-of-way and any constraints;
- Designing the traveled way and roadside elements, including an evaluation of trade-offs as may be necessary if right-of-way is constrained;
- Designing the street-side elements, which requires an understanding of the characteristics and activity of the adjacent existing or future context; and
- Assembling the roadway components—an iterative process, particularly in constrained rights-of-way, to balance LOS and QOS to all modes.

3.6.3 Urban Street Design Guidelines, City of Charlotte, North Carolina

The City of Charlotte's USDG are based on the understanding that various stakeholders have different expectations of what makes streets “good” or even “great” (FHWA n.d.b, City of Charlotte 2007b). The USDG guidelines stress that the design team must assess the expectations of a variety of stakeholders for the final street design and operations to ensure that the design best reflects the roadway's contexts and intended functions. Charlotte also uses the guidelines to ensure that the design of the city's streets provides for the safety and comfort of all users to the best extent possible.

The six-step process outlined in the USDG consolidates traditional city planning, urban design and transportation planning activities into a sequence of fact-finding and decision-making steps. This process for planning and designing streets was intended to support the creation of “more streets for more people” (City of Charlotte 2007b). The identified performance outcomes of the USDG process include (City of Charlotte 2007b):

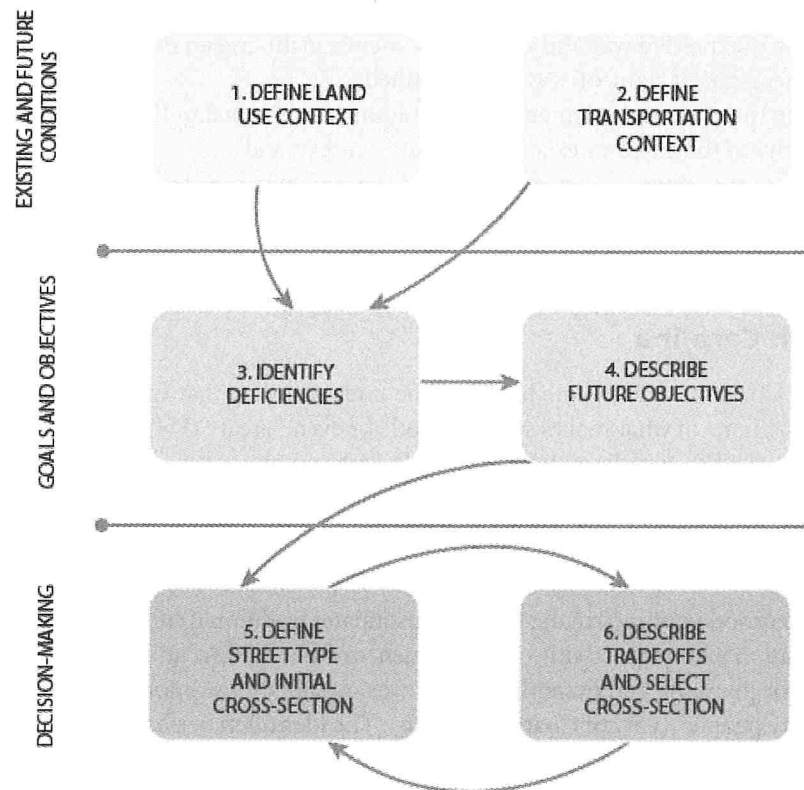
1. Ensuring that the perspectives of all stakeholders interested or affected by streets are seriously considered during both the planning and design process for existing or future streets;
2. Defining a clear sequence of activities to be undertaken by staff, consultants and stakeholders;
3. Remembering that this . . . process . . . is much more geared toward [achieving future goals and outcomes rather than what currently exists and how streets were designed in the past];
4. Verifying that the inevitable trade-offs affecting objectives, benefits, costs, and impacts are well documented so that the recommendations made by staff, [design] consultants or stakeholders are based on understanding the direct effects on specific modes of travel and/or land use intentions; and
5. Always striving to create not only more streets, but also more complete streets that are good for all modes of travel, and even some great streets that are remarkable because of the very effective and favorable ways that the adjacent land uses and transportation functions of those streets support each other.

The design process described in the USDG provides great flexibility to decision makers “to ensure that the resulting streets are appropriately based on the existing and proposed land use and transportation contexts” (City of Charlotte 2007b). This flexibility can encourage creative solutions as land use planners, transportation planners and engineers collaborate in thinking through the implications of alternative street designs.

In Charlotte, the six-step process has primarily been applied to planning and designing the “non-local” street types (e.g., main streets, avenues, boulevards, and parkways) that typically have functional classifications as arterial and collector roadways. Exhibit 3-11 outlines the six-step process.

Charlotte's approach to project design starts with area planning, which provides “opportunities to integrate the planned land use and transportation characteristics on an area-wide network basis” (City of Charlotte 2007b). If sufficient information is available about future land use context and future transportation context, the USDG encourages the planning team to “specify the actual cross sections for all non-local streets in the area plan” while recognizing that “retrofitting a non-local street with limited right-of-way through an existing neighborhood will be more complicated and require a more rigorous design alternatives trade-off analysis” (City of Charlotte 2007b).

Exhibit 3-11. The six-step process for applying Charlotte's USDG.



Source: Urban Street Design Guidelines (City of Charlotte 2007b)

3.6.4 Applying the Six-step USDG Process

Three assumptions are built into the USDG six-step process (City of Charlotte 2007b):

1. The process will involve a variety of stakeholders. The number of stakeholders and discussions will vary, depending on the magnitude and consequences of the street(s) to be designed.
2. The resulting street will be as “complete” a street as possible, in order to meet [the city’s multimodal objectives].
3. The steps in the decision-making process will be well documented. The documentation will clearly describe the major trade-offs made among competing design elements, how those were discussed and weighed against each other, and the preliminary and final outcomes. Thorough documentation will ensure that all stakeholders’ perspectives are adequately considered in the final design.

In the six-step process, the first four steps encompass an area-wide approach to gathering and assessing the required information, because urban and suburban streets typically are embedded within a surrounding street network and context of land uses. The balance of this section presents the six steps, as described in the USDG (City of Charlotte 2007b):

Step 1: Define the Existing and Future Land Use and Urban Design Context

The classification and ultimate design of any street should reflect both the existing and expected future land use contexts. These existing and future contexts should be considered from the broadest, area-wide perspective down to the details of the immediately adjacent land uses. A street is likely to be classified and/or designed differently if it is in an area planned for higher density development, such as a transit station area, versus in [a neighborhood with limited development changes anticipated].

The following questions regarding the intensity and arrangement of existing and future land uses in the area surrounding the street to be designed should be addressed by the plan/design team:

- What does the area look like today?
- What are today's land use mixtures and densities?
- What are the typical building types, their scale, setbacks, urban design characteristics, relation to street, any special amenities, etc.?
- Are there any particular development pressures on the area (the nature of this may vary according to whether the area is a "greenfield" versus an infill area and this type of information is particularly important in the absence of an area plan)? What, if anything, can be gleaned from permit data, for example, about the nature of the emerging land use context?
- What are the "functions" and the general circulation framework of the neighborhood and adjacent areas?
- Is there a detailed plan for the area?
- If so, what does the adopted, detailed plan envision for the future of the area?
- Does the plan make specific recommendations regarding densities, setbacks, urban design, etc.?
- Are there any other adopted development policies that would affect the classification of the street segment?

Step 2: Define the Existing and Future Transportation Context

The transportation assessment should consider both the existing and expected future conditions of the transportation network adjacent to or affecting the street to be designed. The recommended design should reflect the entire transportation context (function, multimodal features, form), rather than that related strictly to capacity on a given segment.

The following questions regarding existing and future transportation conditions should be addressed by the plan/design team:

- What is the character of the existing street? How does the street currently relate to the adjacent land uses?
- How does the street currently function? What are the daily and hourly traffic volumes? Operating and posted speeds? What is the [LOS] for pedestrians? Cyclist? Motorists?
- What are the current design features, including number of lanes, sidewalk availability, bicycle facilities, traffic control features, street trees, etc.?
- What, if any, transit services are provided? Where are the transit stops?
- What is the relationship between the street segment being analyzed and the surrounding network (streets, sidewalks, transit, and bicycle connections)?
- Are there any programmed or planned transportation projects in the area that would affect the street segment?
- Are there any other adopted transportation policies that would affect the classification of the street segment?

Step 3: Identify Deficiencies

Once the existing and future land use and transportation contexts are clearly defined and understood from an area-wide perspective, the plan/design team should be able to identify and describe any deficiencies that could/should be addressed by the new or modified street. This step should consider all modes and the relationship between the transportation and the land use contexts.

From the information provided in the first two steps, "deficiencies" might include, but are not limited to:

- Gaps in the bicycle or pedestrian network near or along the street segment;
- Gaps in the bicycle or pedestrian network in the area (which may increase the need for facilities on the segment because of the lack of alternative routes);
- Insufficient pedestrian or bicycle facilities (in poor repair, poorly lighted, or not well buffered from traffic);
- Gaps in the overall street network (this includes the amount of connectivity in the area, as well as any obvious capacity issues on other segments in the area . . .);
- Inconsistencies between the amount or type of transit service provided along the street segment and the types of facilities and/or land uses adjacent to the street; and
- Inconsistencies between the existing land uses and the features of the existing or planned street network.

Step 4: Describe Future Objectives

This step synthesizes the information from the previous steps into defined objectives for the street project. The objectives could be derived from the plans and/or policies for the area around the street, as well as from the previously identified list of deficiencies. The objectives will form the basis for the street classification and design.

In addition to the general intent of providing complete streets, the following issues should be considered in defining the specific objectives:

- What existing policies might or should influence the specific objectives for the street?
- What conditions are expected to stay the same (or, more importantly, what conditions *should* stay the same)?
- Would the community and the stakeholders like the street and the neighborhood to stay the same or to change?
- Why and how would the community and the stakeholders like the street and the neighborhood to change?
- Given this, what conditions are likely to change as a result of classifying the street (exactly how will the street classification and design support the stakeholders' expectations)?

Step 5: Recommend Street Classification and Test Initial Cross Section

At this point, the plan/design team recommends the appropriate USDG street typology. . . . [Charlotte's guidelines use street "typologies" that are used based on the previous steps.] The rationale behind the classification should be documented. **This step should also include a recommendation for any necessary adjustments to the land use plan/policy and/or transportation plan for that area.** Since the street type and the ultimate design are defined, in part, according to the land use context, subsequent land use decisions should reflect and support the agreed-upon street type and design.

The initial cross section should be defined based on the recommended street typology, keeping in mind that some typologies allow more than one option. Once the preferred option is identified, the ideal cross section will typically include the design features with their preferred dimensions specified for that street type.

The initial cross section should then be tested against the land use and transportation contexts and the defined objectives for the street project. At this point, any constraints to the provision of the initial preferred cross section should also be identified, including:

- Lack of right-of way,
- Existing structures,
- Existing trees or other environmental features,
- Topography, and
- Location and number of driveways.

This step should clearly identify which constraints may prohibit the use or require refinement of the initially defined cross section.

Step 6: Describe Trade-offs and Select Cross Section

If the initial, "preferred" cross section can be applied, then this step is easy: the initial cross section is the recommended cross section. In many cases, though, the initial cross section will need to be refined to better address the land use and transportation objectives, given the constraints identified in Step 5. Sometimes, the technical team will develop more than one alternative design. **In that case, these multiple alternatives should be presented to the stakeholders for their input.**

Any refinements to the initial cross section (or alternatives) should result from a thoughtful consideration of trade-offs among competing uses of the existing or future public right-of-way [from all user perspectives]. The trade-offs should be related to the requirements of each group of stakeholders and the variety of design elements that can best accommodate those requirements. [A matrix in the USDG document provides a] listing of the general expectations of various stakeholders about streets and the elements that might achieve those expectations. *At the least*, the requirements and elements listed in that matrix should be considered in any trade-off discussion, though that list should not be considered comprehensive.

The specific method of evaluating the trade-offs is left open to the plan/design team, as long as the method/discussion/analysis is documented. All perspectives should receive equal consideration and accountability in the planning and design process. Proper documentation will also generate information useful for future street design projects that might have similar characteristics, objectives, or constraints.

Once the trade-offs are evaluated, the team should be able to develop a refined cross section and suggested design treatments. The culmination of all the previous steps, including any additional stakeholder comments, should provide sufficient rationale to select the design alternative that best matches the context and future expectations for the street project.

The steps outlined in Charlotte's USDG suggest that there is a linear process leading to an ideal solution. Realistically, in some instances the process may not follow the exact sequence described above. Some information may not be available or may not be applicable to project conditions. Nonetheless, the intent of the six-step process is to ensure that the existing and future contexts are given adequate consideration, that any related plans are modified to reflect the outcome, and that all perspectives are given equal consideration in the process.

The approach described in this Guide for large-scale street projects also can be applied to smaller-scale or short-term projects or processes. In those cases, an "abbreviated" version of the six steps can be used to reach decisions. An abbreviated process will necessarily involve a shorter timeframe and will likely involve fewer stakeholders, but it is still important to consider all user perspectives and document any necessary trade-offs. The intent is to apply this thought process to the design of a city's emerging multimodal street network in a way that accounts for all users, whether the full six-step process is followed or an abbreviated version.

3.6.5 NCHRP Research Report 839: A Performance-Based Highway Geometric Design Process

NCHRP Research Report 839 (Neuman et al. 2017) outlines a recommended geometric design process for performance-based design. The report notes that successful completion of critical parts of the overall design process are essential to the success of the roadway design process.

NCHRP Research Report 839 also references *NCHRP Report 480: A Guide to Best Practices for Achieving Context Sensitive Solutions* (Neuman et al. 2002), noting the earlier report's documentation of a project development framework that reflects the recent evolution of roadway design. *NCHRP Report 480* suggests that the critical success factors to roadway project completion are to:

- Employ an effective decision-making process;
- Reflect community values (i.e., include stakeholders);
- Be environmentally sensitive; and
- Implement safe and feasible solutions.

NCHRP Research Report 839 suggests that these critical success factors align well with the goals of performance-based design, and that they are reflected in the following recommended steps of the roadway design development process (Neuman et al. 2017):

- Step 1: Define the transportation problem or need;
- Step 2: Identify and charter all project stakeholders, including:
 - Internal agency stakeholders,
 - External agency stakeholders,
 - Other external stakeholder groups or agencies, and
 - Directly affected stakeholders.
- Step 3: Develop the project scope, including refinement and confirmation of the project's Problem Statement or Needs Statement;
- Step 4: Determine the project type and design development parameters;
- Step 5: Establish the project's context and geometric design framework, including:
 - A framework for the geometric design process for new construction and reconstruction,
 - Project evaluation criteria (developed within the context and framework),
 - Decision-making roles and responsibilities,
 - Basic geometric design controls (e.g., design or target speed), and
 - Basic design controls (e.g., design traffic volumes, design LOS or operating condition, and road user attributes).
- Step 6: Apply the appropriate geometric design process and criteria for
 - Roads on new alignment, which are designed with a unique process and set of criteria,
 - Projects involving existing roads (e.g., reconstruction, 3R), and
 - Developing a project technical approach.

- Step 7: Designing the geometric alternatives, which involves
 - Assembling an inclusive and interdisciplinary team,
 - Focusing on and addressing the need (or solving the problems) within the project’s context conditions and constraints.
- Step 8: Design decision-making and documentation, including independent quality and risk-management processes; and
- Step 9: Transitioning to preliminary and final engineering of selected alternative design criteria, elements and features.

NCHRP Research Report 839 also presents two additional steps. The additional steps relate primarily to agency operations and maintenance, however, and they are not discussed in this Guide.

3.7 Balancing MMLOS

As summarized by Exhibit 3-3, numerous tools are available to designers as they develop and evaluate various service levels and performance metrics for all users in multimodal projects. Some of these tools require significant data collection and analysis, whereas others require substantially less data and are more qualitative. Using these tools can provide a wealth of information about the level, quality and performance of each mode served by a project design alternative; however, deciding which tool is best for each specific project can be a challenge.

The type and depth of MMLOS and multimodal QOS analysis used in the geometric design process can vary widely. A designer’s choices are influenced by several factors, including but not limited to:

- Project funding, budget and source;
- Project type and size;
- Desired performance outcomes;
- Demand level of modes (existing and planned);
- Project context (existing and planned);
- Community or corridor plans, goals and policies;
- Community issues and concerns;
- Condition of current roadway(s);
- Right(s)-of-way available; and
- Utility conditions.

The most important aspects of the selected design evaluation approach are that the needs, desires and performance goals of all legal users are identified at some level, and that they are considered as an integral part of the design process.

Understanding current and future user demands, how those user movements interact with and affect each other, and how performance across all modes is affected by the various design alternatives is essential to achieving a well-balanced and effective multimodal design. Trade-offs in LOS, QOS and other performance metrics normally will be required to determine the “best-fit” design alternative given the project’s purpose and need and the community’s priorities.

3.7.1 The North Carolina Complete Streets Planning and Design Guidelines

The *North Carolina Complete Streets Planning and Design Guidelines* (North Carolina DOT 2012) recommends that all identified design alternatives be tested against the land use and transportation context and the range of objectives and outcomes for the project to determine any

inconsistencies or constraints. The *Complete Streets* guidelines note that solutions within various alternative scenarios will likely vary by cost, right-of-way needs and/or how various modes are accommodated, and that, preferably, these variations will require an evaluation and description of trade-offs before selection of the recommended alternative.

Ideally, the evaluation and description of trade-offs will have been considered or conducted during the participatory stakeholder process required to meet NEPA requirements. It should occur prior to publication of any NEPA document. While preliminary design concepts are under development, it is feasible to make a broad comparison of trade-offs in travel way and roadside cross sections, right-of-way needs, ability of the alternatives to meet the identified objectives, and so forth. By the end of this process, the reasons behind the selected cross section should be transparent and understood by all stakeholders. North Carolina's guidelines recommend that, at a minimum, the following items be considered (North Carolina DOT 2012):

- Consistency with local context, land use and transportation plans and policies, and project objectives . . . ;
- Balanced modal capability (to achieve functionality for all users);
- Accessibility to achieve functionality for all users;
- Right-of-way availability;
- Environmental (natural and human) considerations; and
- Overall cost.

3.7.2 Balancing MMLOS for Large and Complex Projects

Larger, more costly and more complex projects including accommodation for non-motorized users generally will benefit from investing in the 2016 HCM 6th Ed.'s multimodal analysis applications using the medium-level analysis methods. In addition to providing performance measures and computational methods for motorized vehicles, the HCM 6th Ed. also provides a variety of measures that can be used for pedestrians and bicycles on differing on- and off-street facilities. As research has not yet been conducted to quantify the pedestrian and bicycle experience for all types of HCM system elements, not every mode is addressed in every section of the pedestrian, bicycle and transit analysis and guidance. (For more discussion on use of the HCM for multimodal analysis, see the section on current practice in this chapter of the Guide.)

The HCM's pedestrian and bicycle performance measures focus on (1) the impacts of other facility users on pedestrians and bicyclists and (2) facility design and operation features under the control of a transportation agency. Some analysts may also be interested in the effects of urban design on pedestrians' and bicyclists' potential comfort and enjoyment while using a facility. In those cases, additional measures, such as the Mineta Transportation Institute's *Low-Stress Bicycling and Network Connectivity* report (MTI 2012), HPE's Walkability Index (ITE 2010b) or the BEQI (SFDPH 2009, SFDPH 2012) could be appropriate tools for additional analysis.

The HCM also provides a transit LOS measure for evaluating on-street public transit service in a multimodal context. The TCQSM 3d Ed. provides a variety of performance measures, computational methods and spreadsheet tools to evaluate the capacity, speed, reliability and QOS of on- and off-street transit service (Kittelson and Associates, Inc., et al. 2013).

The four-volume HCM provides the most detailed analysis tools available to the designer. Volume 3, "Interrupted Flow," addresses urban street facilities in Chapter 16. Volume 4, the "Applications Guide," includes thirteen separate supplemental chapters. Among these supplemental chapters, Chapter 29, "Urban Street Facilities: Supplemental" can be used as a companion chapter to Volume 3, Chapter 16.

Volume 4, Chapter 29 uses five example problems to demonstrate the application of the methodologies to conduct a multimodal evaluation of urban street performance and an evaluation of urban street reliability. The examples illustrate the multimodal facility evaluation process. Four

of the examples demonstrate an operational level analysis, and the fifth example demonstrates a planning-level analysis. The planning and preliminary engineering analysis is identical to the operational-level analysis in terms of the calculations, except that default values are used when field-measured values are not available. The examples address the following project scenarios:

- Automobile-oriented urban street (operational-level analysis);
- Widen the sidewalks and add bicycle lanes on both sides of facility (operational-level analysis);
- Widen the sidewalks and add parking on both sides of facility (operational-level analysis);
- Urban street reliability under existing conditions (operational-level analysis) and
- Urban street reliability strategy evaluation (using planning-level analysis).

Each example calculates individual modal levels of service, but they are not typically combined into a single comprehensive LOS for the project because there is concern that doing so would disguise the disparities in the perceptions of QOS for the individual modes. This Guide suggests that each project be analyzed specific to its context, expected user modes and area characteristics. Because no two projects are the same, a comprehensive LOS could thwart the goals of meeting the LOS or QOS of a vulnerable user.

3.8 Design Process in Constrained Rights-of-Way

A primary roadway design challenge is balancing all of the desired design elements of the roadway within the available or planned right-of-way. The roadway design process will assist in determining the desired elements to serve all users within the cross section, but actual conditions often limit the width of the traveled way and roadside such that difficult choices must be made. Designing roadways in constrained rights-of-way requires prioritizing the design elements and emphasizing the higher priority elements in constrained conditions. Higher-priority design elements are those considered critical to making the roadway meet the primary vision and context-sensitive objectives of the community. Lower-priority elements also are important, but have less influence on achieving the objectives and can be removed in situations with insufficient right-of-way.

In urban and suburban contexts, the width of the public right-of-way often varies along the roadway, making the designers' choices even more challenging. When the width of the right-of-way is limited or varies throughout a project, it is useful to prioritize design elements and develop a series of varying cross sections that are categorized as follows:

- Optimal conditions (i.e., sections without right-of-way constraints that can accommodate all desirable elements);
- Predominant (i.e., sections of the predominant right-of-way width in the corridor that can accommodate all of the higher priority elements);
- Functional minimum (i.e., typically constrained sections that can accommodate most of the higher priority elements); and
- Absolute minimum (i.e., severely constrained sections that can accommodate only the highest-priority design elements without changing the type of roadway).

If roadway sections are sufficiently constrained that they fall below the absolute minimum, or if most sections of the right-of-way are categorized at or below the absolute minimum, the designer should consider (1) changing the roadway to a different type while attempting to maintain basic function, (2) converting the roadway to a pair of one-way roadways (a couplet) or (3) seeking other solutions that achieve the community vision. These options may require revisiting some of the earlier steps of the design process, potentially even requiring a review of the community vision for the roadway and the area transportation plan or identifying a new context zone/roadway relationship. If the vision for the corridor is long range, then the necessary right-of-way may need to be attained over time as the adjacent properties redevelop. Under these circumstances, the optimal

(or the predominant) roadway width can be phased in over time, beginning with the functional or absolute minimum design in the initial phase.

Given constrained conditions, it might be tempting to minimize the roadside width and provide only the minimum pedestrian throughway (5 ft.). In urban areas, however, even under constrained conditions, it is critical to provide at least a minimum-width furnishings zone to accommodate street trees, utility poles and other appurtenances. If a furnishings zone is not provided, trees, utilities, benches, shelters and other street paraphernalia might encroach into the throughway for pedestrians or result in an inadequate roadside width when the community's vision for the context zone is ultimately achieved.

Sources of Additional Information

- These publications supplement the sources listed at the end of Chapters 1 and 2.
- AASHTO. 2010. *Highway Safety Manual (HSM)*, with 2014 supplement. American Association of State Highways and Transportation Officials, Washington, D.C.
- Cambridge Systematics, Inc. and High Street Consulting Group. *NCHRP Report 660: Transportation Performance Management: Insight from Practitioners*. Transportation Research Board of the National Academies, Washington, D.C., 2010.
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CHAPTER 4

Traveled Way Design Guidelines

4.1 General Considerations for Traveled Way Design for All Users

The discussion in this section provides information and guidance to the design process for the traveled way of any roadway and street project serving a mix of users with a vehicle design speed of 45 mph or lower.

4.1.1 Roadway Uses, Users and Activities in Low- and Intermediate-Speed Environments

As discussed in previous chapters of this Guide, designing road and street facilities that effectively serve all current and planned users in low- and intermediate-speed environments can be a challenging process. Often, minimum and desirable vehicle-focused geometric design criteria and dimensions are required or suggested by local, state and federal manuals and guidelines. In many project locations, these criteria and dimensions are not attainable, attainable only at significant cost, or providing them may negatively impact conditions for other users of the right-of-way. Nonetheless, considerable flexibility is available to the designer in evaluating and making these often-difficult trade-offs in design criteria and dimensions.

Pedestrians are the most vulnerable roadway users because they are at the greatest risk of injury or death in a collision with someone traveling by any other mode. Bicyclists generally travel at slower speeds than motorized vehicles and are inherently more vulnerable in the event of a crash with a car, truck or transit vehicle. Improving the LOS, QOS or performance for one user mode may negatively affect those same elements for one or more of the other modes. Certainly, technical analysis driven by quantitative data can provide useful information to the designer about the impacts of these design choices and modal interactions, but no single process tool can make absolute choices for a “best fit” design solution to meet a project’s purpose and need.

Balancing and blending modal accommodation in the geometric design process often involves technical analysis supported by a qualitative, even subjective, process that involves policy choices, engineering judgment and the use of flexible and unique design approaches. This Guide identifies the ranges of flexibility that are available in current national design practice and provides guidelines for how to apply that flexibility. Greater awareness of the flexibility and versatility available in national guidance will help designers overcome many challenges related to both new and retrofit project designs.

This chapter addresses criteria for a wide range of elements that may be involved in the design of a traveled way that serves motorized vehicles, including trucks, transit and possibly bicycles, in low- and intermediate-speed environments. Chapter 5 addresses criteria for design of roadside

areas adjacent to the traveled way and which may include facilities for pedestrians, bicyclists, transit access and other elements that support the land use context.

4.1.2 Relationship of Traveled Way and Roadside Environments

A roadway design project may involve improvements to the traveled way, to the roadsides, or to both the traveled way and the roadsides. Even if a design project involves only one of these two realms, consideration of the other realm is essential to the design process because of the proximity and interaction of the traveled way with the roadside. Land use context creates a third realm that also should be considered in the design process because the context informs the designer how the land use is served by, and relates to, all users of both the traveled way and roadsides.

This chapter addresses design elements and criteria for a traveled way that serves:

- Motorized vehicle users (moving and parked),
- Bicycle users (in some but not all possible settings), and
- Pedestrians (e.g., on shoulders where sidewalks do not exist and shoulders may be the only all-weather travel surfaces available to them).

Although shoulders are not substitutes for a well-designed separated pedestrian facility in the roadside, the need may occasionally arise to design shoulders as walkways where roadside space or funding is constrained. The FHWA memorandum titled *ACTION: Consideration and Implementation of Proven Safety Countermeasures* states that “walkable shoulders (minimum of 4 ft. stabilized or paved surface) should be provided along both sides of rural highways routinely used by pedestrians” (FHWA 2008).

This Guide presents design guidance for the traveled way, roadside and intersections in three distinct chapters, but all three design environments usually have many interrelationships involving multiple modal users. Therefore, the full right-of-way cross section and intersection design development process should be integrated as alternatives are developed and analyzed.

4.1.3 Understanding Context and Multimodal Relationships

Understanding context is considered a necessary element of effective multimodal roadway design (see Chapter 2). This is especially true for the traveled way component of the roadway because of the interactions of non-motorized users who share the traveled way, travel adjacent to the roadway, and cross it at intersections and non-intersection locations.

This Guide presents design guidance that requires a thorough understanding of the existing and future context of a project area and how that context affects multimodal activity within and adjacent to the roadway project limits. The application of context also requires a designer to know how to apply geometric design controls and criteria of the roadway to support beneficial interactions between the roadway, roadside and existing and planned multimodal activity generated by adjacent land uses and local modal networks.

To the extent possible, land use context and multimodal demand should be considered during the earliest stages of project development so that these needs can be addressed before the preliminary and final design stages. The designer also should recognize that existing and future context are both important design considerations, much as existing and future vehicle design hour volumes are important for determining vehicle needs. Finally, designers should realize that context—which may be defined initially as a specific context zone category for a project—often will vary within each general context zone. Context zones also may vary throughout the limits of a roadway project. The combination of multimodal functions, land use context, network

needs, community goals and other factors may cause the design concept, cross section and design elements to vary throughout the roadway's length.

Project alternatives should emerge from a full understanding of the relationships between the roadway, the adjoining properties, the character of the broader area and other unique project circumstances, values or objectives. Preferably, a roadway project's modal priorities and emphasis will have been clearly identified through the project planning and concept development phases. If this has not occurred, then the design process should address these needs to the extent feasible given the project's scope, budget, available right-of-way and other considerations.

The design process for low- and intermediate-speed multimodal roadways requires an expanded understanding of context beyond elements like on-street parking and access management. Context is highly dependent on many aspects of land use, including building and site design, which can support integrated pedestrian, bicycle and transit activities and environments.

4.1.3.1 *Land Use Types*

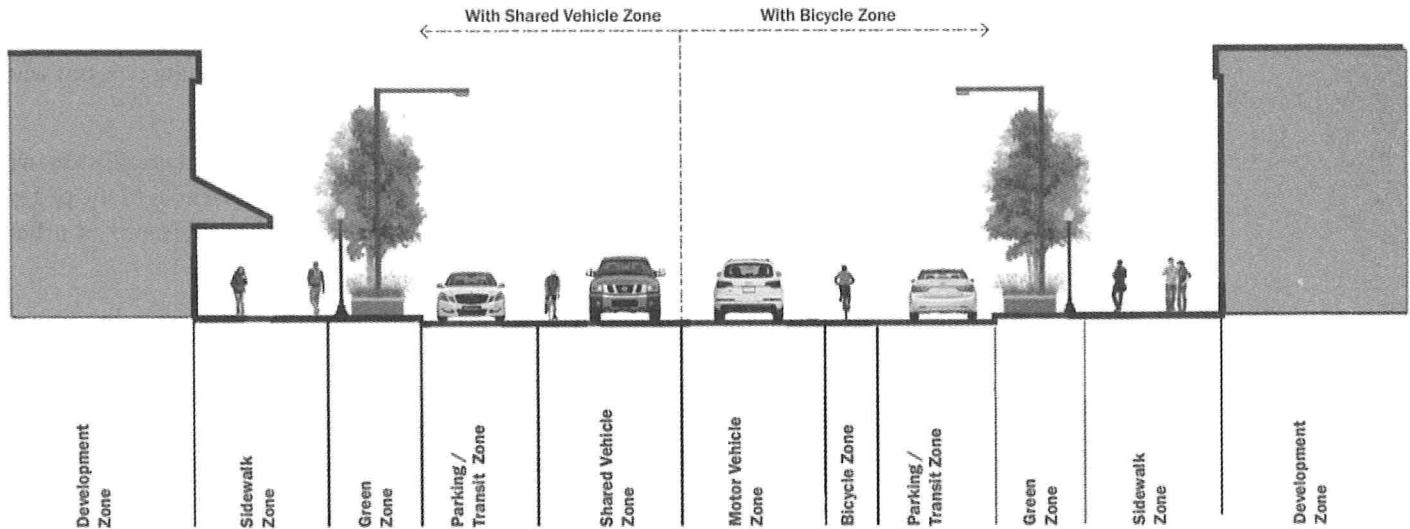
Land use is a common criterion for characterizing development and estimating vehicle trip generation, particularly in vehicle-dominated areas. The design process should recognize land use as an important contributor to the overall project context and as a major factor in the selection of design criteria related to the levels of current and projected motorized and non-motorized travel. Land use also is a key factor in selecting and assembling components of the cross section and determining how the available roadway right-of-way is allocated to particular uses.

In addition to having a fundamental impact on automobile travel demand, variations in adjacent land use will affect the width and design of the roadside, the part of the roadway between the curb or shoulder and the edge of the right-of-way, including sidewalks. Differing land uses have differing needs for design elements such as clear sidewalk space, landscaping, street furniture, bicycle parking and so forth. Commercial uses tend to generate higher volumes of pedestrian and bicycle travel than do office or industrial uses. Typically, commercial areas also have a higher volume of delivery trucks and buses and usually have a higher turnover of on-street parking than do residential areas.

4.1.3.2 *Property Site Design*

The ways in which buildings, circulation, parking and landscaping are arranged on a site affect how adjacent roadsides and roadways should be designed. Ideally, roadway designers understand and are familiar with these relationships. The specific elements of site design that contribute to defining context in non-rural areas include:

- **Building orientation and setback.** In contexts where walking has lower priority, such as traditional low-density suburban contexts, buildings typically are less related to the street, either by having large setbacks into private property or by being oriented toward a parking lot rather than the street. By contrast, in contexts with traditional urban and urban core characteristics, buildings will be oriented toward and often adjacent to the roadway, and these contexts will involve a higher priority for pedestrian and bicycle access. The directness of the multimodal connection to the building entry from the roadway, and how the building may be integrated into the roadside, also varies with differing land use types. In some locations, buildings may form a continuous built edge or street wall (see Exhibits 4-1 and 4-2 for rural village and urban context examples).
- **Parking type and orientation.** Parking provided in surface lots between buildings and roadways typically define a vehicle-dominated context with a lower priority for walking and biking. Conversely, on-street parking, structured parking and parking behind buildings accessed by alleys or side streets is an urban or urban core characteristic. Roadways in these types of contexts will typically have a higher priority for walking and biking.

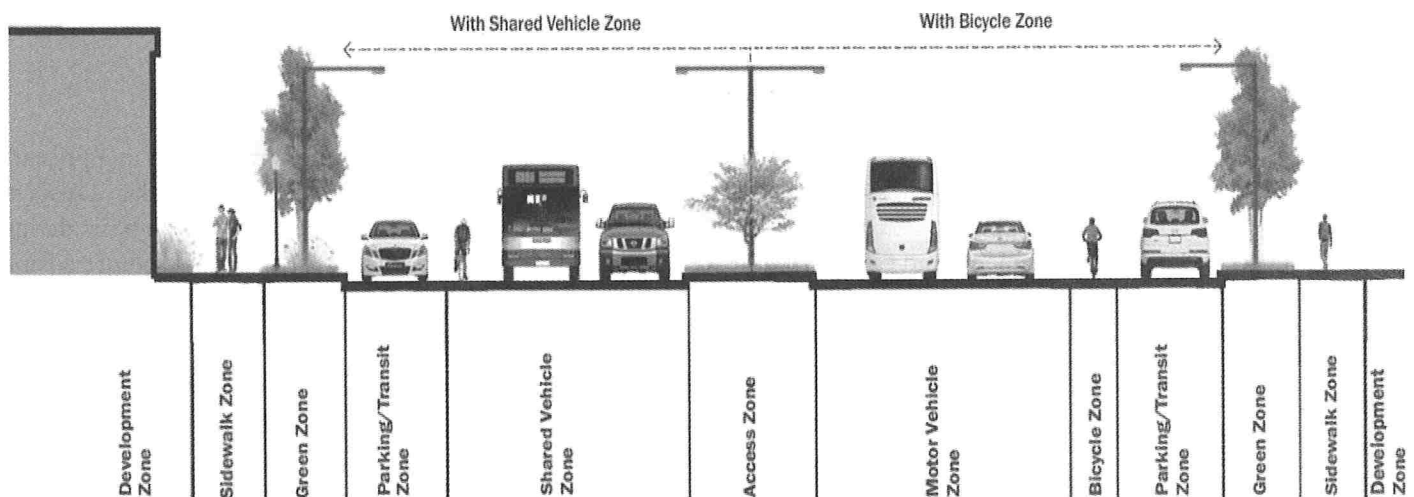
Exhibit 4-1. Components of a typical rural village main street.

Source: North Carolina DOT (2012)

- **Block length.** Development patterns with traditional urban, urban core and many rural town contexts usually have shorter block lengths with a network of closely connected streets and possibly alleys. Vehicle-focused contexts such as suburban and some urban contexts tend to have larger block lengths, fewer street connections and often no alley access. These types of street patterns typically require longer walking distances and will tend to generate lower pedestrian volumes along higher volume roadways. Typically, shorter block lengths can lead to greater accessibility throughout an area for pedestrians.

4.1.3.3 Site Building Design

Building design contributes significantly to context and the priority that the context gives to walking. Building access, height, scale, density, architecture, relationship to adjacent buildings

Exhibit 4-2. Components of a typical urban main street.

Source: North Carolina DOT (2012)

and roadways, and the type of ground-floor land use in multistory buildings affect context and multimodal activity. Contexts that give a lower priority to walking generally are developed to be more internally oriented and may even minimize interaction with adjacent roadsides and sidewalks. The lack of walkability in these contexts is not correlated with building type but with features of building and site design.

In a traditional urban, urban core and even rural town context, buildings typically are oriented toward the street. Ground-floor uses in these buildings are usually oriented to the pedestrian passing on the adjacent sidewalk. Building design elements that contribute to an urban context include:

- **Building height.** Buildings are the primary feature of urban contexts that create a sense of definition and enclosure of a roadway—an important urban design element that helps create the experience of being in a city and in a place that is comfortable for pedestrians. Highly multimodal roadways do not require tall buildings. Street trees may be used to provide a similar sense of definition and enclosure in contexts with lower height and less density of buildings.
- **Building width.** Like building height, building width contributes to the sense of enclosure of the roadway right-of-way. There are three elements of width: (1) the percentage of a building's width fronting the street, (2) the distance between buildings (building separation), and (3) building configurations. As with building height, greater building width along a roadway tends to create a sense of definition and enclosure of the corridor. This feeling of enclosure contributes to drivers feeling more comfortable operating at lower travel speeds.
- **Building scale and variety.** The scale and variety of buildings help define the context and character of a roadway and encourages walking by providing visual interest to the roadway. The scale and variety of buildings should help define the scale of the pedestrian environment. Vehicle-oriented building scale maximizes physical and visual accessibility by drivers and passengers of motorized vehicles, contributing to contexts that discourage walking.
- **Building entries.** Building entries are important in making buildings accessible and interesting for pedestrians. To maintain or create traditional urban character, buildings should have frequent entries directly from adjacent roadways to improve connectivity and to break down the scale of the building. Frequent entries from parking lots and secondary roadways should be provided as well.

More information on how building design relates to context can be found in the ITE publication, *Promoting Sustainable Transportation Through Site Design* (ITE 2004) and in the *SmartCode* from the Center for Applied Transect Studies (CATS 2003).

4.1.3.4 Selecting Context Zone(s) in Roadway Traveled Way Design

The design process presented in this Guide uses a group of four context zones as a primary initial consideration in selecting the design elements and criteria for multimodal roadways. As emphasized throughout this document, context helps guide the selection of basic design elements and criteria for low- and intermediate-speed roadways with a mix of motorized and non-motorized users. This chapter focuses on guidelines that help the practitioner identify and select context zones as one of the first steps in the design process.

Exhibit 4-3 defines context in five context zone categories (as recommended in NCHRP 15-52). All but the rural context zone are addressed in the Guide. Deciding which context zone to use for a particular project, or combination of contexts, can be difficult for some projects. The designer also should consider land use or modal variations within each context zone when developing cross section and design elements.

Exhibit 4-3. Land use context zones.

Context Category	Density	Land Use Character	Setback	Typical Level of Multimodal Activity
Rural	Lowest (few houses or other structures)	Agricultural natural resource preservation and outdoor recreation uses with some isolated residential and commercial	Usually large setbacks	Low or Very Low
Rural Town	Low to medium (single family houses and other single purpose structures)	Primarily commercial uses along a main street (some adjacent single family residential)	On-street parking and sidewalks with predominately small setbacks	Low to Moderate
Suburban	Low to medium (single and multifamily structures and multistory commercial)	Mixed residential neighborhood and commercial clusters (includes town centers, commercial corridors, big box commercial and light industrial)	Varied setbacks with some sidewalks and mostly off-street parking	Low to Moderate; possibly High in school and recreation settings
Urban	High (multistory, low rise structures with designated off-street parking)	Mixed residential and commercial uses, with some institutional and industrial and prominent destinations	Minimum on-street parking and sidewalks with closely mixed setbacks	Moderate to High
Urban Core	Highest (multistory and high-rise structures)	Mixed commercial, residential and institutional uses within and among predominately high-rise structures	Small setbacks with sidewalks and pedestrian plazas	High to Very High

Source: Stamatiadis et al. (2017)

Guidelines for selecting the context to be used to inform the geometric design process include the following:

- Consider both the existing conditions and the plans for the future, recognizing that roadway improvements usually last longer than development;
- Assess area plans and review general, comprehensive and specific plans, zoning codes and community goals and objectives which may provide detailed guidance on the vision for the area;
- Compare the area's predominant land use patterns, building types and land uses to the characteristics presented in Exhibit 4-3;
- Pay particular attention to residential densities and building type, commercial floor-area ratios and building heights;
- Consider dividing the area into two or more context zones if a range of land use characteristics suggests multiple context zone types; and
- Identify current levels of pedestrian, bicycle and transit activity, and estimate future levels and circulation needs based on the type, mix and proximity of land uses.

4.1.4 Multimodal Network Considerations

Project design usually takes place at a much smaller scale than design at the network level, but in the design of multimodal projects it is important to understand the network role of the facility on which the project is located. A roadway's functional classification (arterial, collector, local) as defined in the federal, state and regional transportation planning processes is a primary network consideration. These designations are based solely on the mobility of motorized vehicles; they

do not address a facility's role in the mobility of other modes, or how the facility relates to the community and the adjacent land use context.

Ideally, network planning is integrated into a comprehensive planning process that concurrently addresses land use, transportation and environmental needs. In practice, especially in regions with multiple jurisdictions, network planning is often conducted in a piecemeal manner by multiple agencies with different geographic jurisdictions, missions and powers. For the practitioner planning or designing a roadway segment, considering network design and function can lead to solutions that help to balance demands for vehicle capacity and support for community goals.

The geometric design process should recognize the role of a roadway as part of at least one, and potentially several, plans, from large-scale vehicle-focused network plans (such as the U.S.DOT's NHS Plan) to more multimodal local neighborhood and corridor plans. The project design process needs to consider the planned state, regional, sub-regional and neighborhood functions of the roadway facility in relation to context and community goals and values. The design of the individual roadway project, therefore, is guided by both its context and the performance of the network. A multimodal network facility may identify some roadways that emphasize vehicles or trucks and others that emphasize pedestrians and transit.

One difficult situation that is often encountered in the design of projects on arterial roadways (and some collector roadways) is the tension between local residents' and communities' desire to emphasize livability, character, walkability, bikeability and other non-vehicle mobility goals and transportation agencies' desire to emphasize vehicle capacity or accommodation of projected regional travel demand. This tension is best addressed through consideration of the broader network and corridor in conjunction with the individual roadway.

Network goals and considerations may be informed by several levels of network plans, as described in Exhibit 4-4. The role that the design facility serves in each of these modal network levels will influence the geometric design of that facility. For example, a design project on a state and federal-aid highway route in an urban region may have multiple goals for multiple modes including the multiple layers of planning goals established by federal, state, regional and local agencies.

Exhibit 4-4. Planning documents that address modal elements in project design.

Type of Transportation Network Plan	Possible Modal Plan Elements					
	Light Vehicle	Freight	Transit	Bicycle	Pedestrian	Other Community Goals *
Federal: NHS Plan	X	X				
State Transportation Plans	X	X	X	X	X	
Regional Transportation Plans (MPO/TPO)	X	X	X	X	X	X
Local Transportation Plans (County/City)	X		X	X	X	X
Transit Agency Service Plans			X			
Community Plans	X		X	X	X	X
Corridor Plans	X	X	X	X	X	X
Neighborhood Plans	X		X	X	X	X

*Land use (context), urban design, housing, community facilities, recreation, parks/open space, utilities, economic development

4.1.5 Functional Requirements of Multimodal Roadways

Multimodal accommodation can exist on any functional classification of roadway (e.g., arterial, collector, or local), but this Guide primarily addresses accommodation needs on arterial and collector roadways. It is typically on those facilities where user types and volumes, vehicle speeds and context interactions combine to present the most challenging conditions to a designer. However, designers should keep in mind that each roadway design is unique, and the ultimate design needs to address the context, objectives, priorities and design concept established for all aspects of the facility and corridor. Consequently, the unique combination of roadway design elements and criteria developed for a project may differ from the Guide's recommendations for individual design elements and criteria. The process of understanding the relationships between design elements and criteria and balancing them against each other in the design process is the essence of flexibility in the geometric design process.

Exhibit 4-5 shows how basic functional requirements and characteristics for a roadway design may vary as project context changes. In itself, a context zone is not the complete indicator of the presence and level of various modes; however, in general the multimodal activity increases as context changes along the continuum from rural to urban settings. The presence of non-motorized users, together with the context, should directly influence the selection of project design elements and criteria. Although the characteristics for multimodal roadways of all functional classifications have common elements, the roadway's functional classification influences the design characteristics and cross section elements to some degree. Higher order regional routes with longer average trip lengths and higher volumes of vehicles, trucks and buses, will create more vehicle-focused roadway designs even though other users must also be provided reasonable levels of mobility and accommodation. These types of facilities often are the most difficult to design given the significant impacts among modes when particular users are favored in the design trade-off process.

4.1.6 Design Controls for Multimodal Roadways

This section identifies the differences in design process controls used where vehicle capacity is the priority consideration versus where higher levels and QOS to pedestrians, bicycle, and context interaction is the priority consideration.

As discussed in Chapter 2 of this Guide, design controls are physical and operational characteristics that guide the selection of criteria in the design of roadways for users. Some design controls are fixed, including topography and certain user performance characteristics, but many other controls can be influenced through design, and these are determined by the designer. The intent of selecting appropriate design controls is to create design outcomes that best meet the purpose, need and goals of the project.

The AASHTO Green Book and several of its supplemental publications identify the functional classification and type of project location (urban or rural) as a design control and suggest different design criteria for rural and urban locations. Vehicle traffic volumes serve to further refine the design criteria for each location. AASHTO also recognizes the influence that types of locations have on driver and other user characteristics and performance. To reinforce the commitment to designing with all users in mind, the Green Book states that "the designer should keep in mind the overall purpose that the street or highway is intended to serve, as well as the context of the project area" and that "designers should recognize the implications of sharing transportation corridors and are encouraged to consider not only vehicular movement, but also movement of people, distribution of goods, and provision of essential services" (AASHTO 2011a).

Exhibit 4-5. Typical multimodal roadway design characteristics by context zone.

Design Characteristic	Typical Multimodal Roadway Design Characteristics by Context Zone			
	Urban Core	Urban	Suburban	Rural Town
Design Speed	20 mph–30 mph	25 mph–35 mph	30 mph–45 mph	25 mph–45 mph
Target Operating Speed *	20 mph–30 mph	25 mph–35 mph	25 mph–40 mph	25 mph–35 mph
Vehicle Lane Widths	10–11 ft.	10–11 ft.	11–12 ft.	11–12 ft.
Dedicated Turn Lanes	<ul style="list-style-type: none"> • Can have negative impacts on pedestrians/bikes • Often eliminated on lower-volume streets 	<ul style="list-style-type: none"> • Can have negative impacts on pedestrians/bikes • Often eliminated on lower-volume streets 	<ul style="list-style-type: none"> • Can have negative impacts on pedestrians/bikes • Special designs may be needed to minimize pedestrian/bike conflicts 	<ul style="list-style-type: none"> • Can have negative impacts on pedestrians/bikes • Often eliminated on lower-volume streets
Medians	<ul style="list-style-type: none"> • Not typically used due to limited right-of-way • Used on boulevard sections 	<ul style="list-style-type: none"> • Not typically used due to limited right-of-way • Used on boulevard sections and for some pedestrian crossings 	<ul style="list-style-type: none"> • Used often for arterial roadways • Sometimes used for collector boulevards and at some pedestrian crossings 	<ul style="list-style-type: none"> • Rarely used unless for pedestrian crossings
On-Street Parking	<ul style="list-style-type: none"> • Frequently used • Parallel is typical, angle or reverse-angle in some settings 	<ul style="list-style-type: none"> • Selectively used at lower speed ranges • Generally not used for streets with speeds 35 mph and higher 	<ul style="list-style-type: none"> • Rarely used due to safety considerations of speed differentials 	<ul style="list-style-type: none"> • Frequently used if land use includes building fronts on or near right-of-way line
Curb and Gutter	<ul style="list-style-type: none"> • Typical 	<ul style="list-style-type: none"> • Typical 	<ul style="list-style-type: none"> • Typical in developed areas 	<ul style="list-style-type: none"> • Typical if land use includes building fronts on or near right-of-way line
Stormwater Drainage	<ul style="list-style-type: none"> • Typical closed drainage system with curb inlets 	<ul style="list-style-type: none"> • Typical closed drainage system with curb inlets 	<ul style="list-style-type: none"> • Often closed drainage system with curb inlets in developed areas • May include open drainage channels in undeveloped or low-density areas 	<ul style="list-style-type: none"> • Often closed drainage system with curb inlets
Shoulders	<ul style="list-style-type: none"> • Rarely used 	<ul style="list-style-type: none"> • Rarely used 	<ul style="list-style-type: none"> • Rarely used in developed areas • Sometimes used in developing areas • Sometimes used in combination with curbs 	<ul style="list-style-type: none"> • Rarely used when building fronts on or near right-of-way line • Sometimes used in towns with low-density land use
Roadside Width	<ul style="list-style-type: none"> • Typically wide to serve pedestrians, street furniture, transit stops, landscaping, sidewalk cafes, bike parking, etc. 	<ul style="list-style-type: none"> • Usually wide enough to serve pedestrians, transit stops, and landscaping • Wider sections may be needed for areas with street furniture, sidewalk cafes, bike parking, etc. 	<ul style="list-style-type: none"> • Typically wide enough for sidewalks separated from the curb, and landscaping • May also include space for separate bike path or shared-use path and transit stops 	<ul style="list-style-type: none"> • Typically wide enough for sidewalks and possibly street furniture and landscaping

Exhibit 4-5. (Continued).

Design Characteristic	Typical Multimodal Roadway Design Characteristics by Context Zone			
	Urban Core	Urban	Suburban	Rural Town
Landscaping/ Green Infrastructure	<ul style="list-style-type: none"> • Typical, although may be limited in constrained settings 	<ul style="list-style-type: none"> • Typical, although may be limited in constrained settings 	<ul style="list-style-type: none"> • Usually provided at some level, although may be limited or low-maintenance in some settings 	<ul style="list-style-type: none"> • Sometimes provided but typically at low levels due to right-of-way constraints
Pedestrian Facilities **	<ul style="list-style-type: none"> • Typically provided both sides with width aligned to volumes • May be adjacent to curb at low speeds 	<ul style="list-style-type: none"> • Typically provided both sides with width aligned to volumes • May be adjacent to curb at low speeds, generally separated at high speeds 	<ul style="list-style-type: none"> • Typically provided both sides with width aligned to volumes • Typically separated from curb or shoulder due to vehicle speeds 	<ul style="list-style-type: none"> • Typically provided with width aligned to volumes
Bicycle Facilities	<ul style="list-style-type: none"> • Accommodation typically provided on most streets • If not shared lanes, then type/location of facilities determined by bicycle plan 	<ul style="list-style-type: none"> • Accommodation provided on many streets according to bicycle plan • If not shared lanes, then type and location of facility determined by bicycle plan 	<ul style="list-style-type: none"> • Accommodation provided on selected streets as determined by bicycle plan • Shared lanes or separate facilities typical as determined by bicycle plan 	<ul style="list-style-type: none"> • Accommodation sometimes provided as determined by town plan and roadway network plan
Pedestrian/ Bicycle Crossings	<ul style="list-style-type: none"> • Typically provided at most intersections • Some controlled and uncontrolled mid-block crossings 	<ul style="list-style-type: none"> • Typically provided at most intersections • Some controlled and uncontrolled mid-block crossings 	<ul style="list-style-type: none"> • Typically provided at most intersections • Some controlled and uncontrolled mid-block crossings 	<ul style="list-style-type: none"> • Typically provided at most intersections • Some controlled and uncontrolled mid-block crossings
Transit Facilities	<ul style="list-style-type: none"> • Typical, some dedicated bus lanes, some fixed guideway in street right-of-way • Many transit stops, some bus pullouts 	<ul style="list-style-type: none"> • Some routes with dedicated bus lanes or fixed guideway in street right-of-way • Many transit stops and some bus pullouts 	<ul style="list-style-type: none"> • Some routes with bus routes, bus stops, bus pullouts 	<ul style="list-style-type: none"> • Infrequent bus access except for possible rural and paratransit access
Major and Signalized Intersections ***	<ul style="list-style-type: none"> • Frequent use, with ADA-compliant pedestrian signals standard • Possible transit and bicycle priority 	<ul style="list-style-type: none"> • Frequent use, with ADA-compliant pedestrian signals standard • Possible transit and bicycle priority 	<ul style="list-style-type: none"> • Frequent use, with ADA-compliant pedestrian signals standard where pedestrian facilities exist • Possible transit and bicycle priority 	<ul style="list-style-type: none"> • Occasional use • ADA-compliant pedestrian signals should be standard
Driveways	<ul style="list-style-type: none"> • Infrequent due to high land use density and structured parking • Pedestrian and bicycle crossings require careful design 	<ul style="list-style-type: none"> • Moderate levels of private access typical • Pedestrian and bicycle crossings require careful design 	<ul style="list-style-type: none"> • Moderate to high levels of private access typical • Pedestrian and bicycle crossings require careful design 	<ul style="list-style-type: none"> • Infrequent where building fronts on or near right-of-way line • Moderate levels of private access outside of town center • Some properties have open access with no designated driveway access

*Design and target speeds are typically the same in urban and urban core contexts.

**Pedestrian facilities always assumed to meet ADA guidelines for accessibility.

***Roundabouts may be an appropriate intersection alternative in any context zone if pedestrian and bicycle movements are properly designed.

4.1.6.1 AASHTO Design Controls

The Green Book presents the pedestrian's needs as an important factor in roadway design and recommends that attention be paid to the presence of pedestrians in rural and urban areas. Characteristics of pedestrians that serve as design considerations and controls include walking speed, age (young and old), walkway capacity, special needs at intersections and the needs of persons with disabilities. The Green Book also notes that the bicycle is an important element of the design process and provides guidance for reducing crash risk and considering separate facilities where needed. The *Guide for the Planning, Design and Operation of Pedestrian Facilities* (AASHTO 2004b) and *Guide for the Development of Bicycle Facilities* (AASHTO 2014b) expand significantly on the Green Book guidance, presenting factors, criteria and design controls for those modes. This Guide emphasizes pedestrians and bicyclists as a design control in all contexts but particularly in multimodal contexts at design speeds of 45 mph and lower.

The Green Book identifies functional classification and design speed as the primary factors in determining roadway design criteria. Green Book design criteria are separated by both functional classification and context by rural and urban types. The primary differences between the two contexts are the facility operating speeds, the mix and characteristics of the users, and the constraints presented by the surrounding context. The other design controls and criteria that form the basis of AASHTO design policy guidance focus on the following basic controls:

- Design vehicle;
- Vehicle performance (acceleration and deceleration);
- Driver performance (age, reaction time, driving task, guidance and so forth);
- Vehicle traffic characteristics (speed, volume, composition);
- Vehicular capacity and LOS;
- Access control and management;
- Pedestrians and bicyclists;
- Safety; and
- Environment and economics.

In this chapter of the Guide, further discussion of multimodal design considerations for selected AASHTO design controls is provided in specific sections.

- **Functional classification.** Functional classification describes a roadway's theoretical function and role in the network and governs the selection of certain design parameters, although the actual function can vary significantly in urban, suburban and rural town contexts. Functional class may influence some aspects of the roadway, such as its continuity through an area, trip purposes and lengths of trips accommodated, level of land access it serves, type of freight service and types of public transit served (see "Functional Requirements of Multimodal Roadways" in this chapter). It is important to consider these functions in the design of the roadway, but the physical design of the roadway must also support and integrate with the context of the project area and network functions of all other modes.
- **Vehicle capacity and LOS.** The conventional design process uses traffic projections for a 10-year, 20-year, or even longer design-year period and attempts to maximize vehicular operations within that timeframe. A context-based, all-user approach to design also takes vehicle traffic projections and LOS into account, but the demand and service to all other users are also projected over that same timeframe, consistent with any planned changes in context. Only after understanding the future needs of all users and the surrounding land use and community changes can the process of balancing the level, quality and performance of all users be accomplished.

Design that considers all users may emphasize one user over another depending on the context and circumstances. Capacity and vehicular LOS certainly play a role in selecting design criteria, but they are only two of many factors the design practitioner should consider and prioritize in the design of multimodal roadways. In many communities, roadway capacity on

selected corridors and roadway segments is considered a lower priority than other factors, such as walking and biking accessibility, economic development or historical preservation. In those locations, vehicle LOS is a lower priority and higher levels of vehicle congestion are considered acceptable. This community-driven approach to design may sometimes conflict with partner agencies that may focus on conventional design outcomes (such as when a state highway also serves as an important community street).

- **Design speed.** Under the conventional design process, many roadway corridors have been planned and designed to serve high speeds and high traffic volumes. As the contexts and character of these roadways in urban, suburban and rural town settings change over time, the vehicle speeds allowed and encouraged by the vehicle mobility design often become a significant concern to non-motorized users who share the right-of-way, adjacent property owners, surrounding neighborhoods and even entire communities. Posted speed limits established for these roadways using the conventional “85th percentile” method may yield speeds higher than the target operating speed for the facility and are often inappropriate for the multimodal activity, land use context, and community desires for the area. In these cases, traffic engineers and police departments are often tasked with using traffic control devices and increased speed enforcement to attempt to reduce operating speeds. The design speed for a facility should generally be the preferred target operating speed for the facility, consistent with the need to provide safe and convenient accommodation of all current and anticipated users. (See the section on “Speed Management” for additional discussion of methods for managing operating speeds that are considered too high for a facility.)
- **Design vehicle.** The design vehicle influences the design criteria selection for lane width and curb return radii. A conservative approach is to select the largest design vehicle (often WB 50 to WB 67) that could be expected to possibly use a roadway, regardless of the frequency of that use. Given that lane widths and curb return radii can have significant impacts on the crash risk and mobility of non-motorized users, a multimodal design process should include an evaluation of the trade-offs involved in selecting one design vehicle over another. In urban and some suburban settings, it is not always practical or desirable to choose the largest design vehicle that might occasionally use the facility.

Wider lanes and corner radii can easily reduce pedestrian visibility, increase roadway crossing distances, and increase speed of turning vehicles, all of which may be inconsistent with the community vision and the goals and objectives for the roadway. In contrast, selection of a smaller design vehicle in the design of a facility regularly used by large vehicles can invite frequent operational problems. The selected design vehicle should be of a type that will use the facility with considerable frequency. This Guide suggests that two types of design vehicle be considered:

- A design vehicle, which must be regularly accommodated without encroachment into the opposing traffic lanes, and
- A control vehicle, which must be accommodated infrequently, but for which encroachment into the opposing traffic lanes, multiple-point turns, or minor encroachment into the roadside is acceptable.

Regional freight mobility plans may be helpful in determining future truck volumes and types. Ideally, the designer should obtain classification counts to determine the frequency and size of large vehicles and how these numbers may vary over the design period as context changes. In urban core and urban contexts, the selected design vehicle is often a single-unit truck or possibly a transit bus. These vehicle types typically provide higher levels of design flexibility in designing accommodations for multimodal users.

4.1.6.2 Other Design Controls

Other elements in the conventional design process also are important as design controls in multimodal design (e.g., horizontal and vertical alignment, stopping and decision sight distance,

and access management). These design controls will normally be applied in multimodal design as they are in conventional design practice.

- **Horizontal and vertical alignment.** Speed affects the criteria for horizontal and vertical curvature, so design is dependent on the desired operating or target speed. For multimodal roadways, careful consideration must be given to the design of alignments to balance safe vehicular travel with a reasonable operating speed. The Green Book provides guidance on the design of horizontal and vertical alignments for urban streets.
- **Sight distance.** Sight distance is the distance that a driver can see ahead in order to observe and successfully react to a hazard, obstruction, decision point or maneuver. Adequate sight lines remain a fundamental requirement in the design of multimodal urban roadways. The criteria presented in the Green Book for stopping and signalized stop- and yield-controlled intersection sight distances should be used in multimodal roadway design.
- **Access management.** The management of private and public access to multimodal roadways influences geometric design, establishing criteria for intersection and driveway spacing, raised medians and median breaks, and vehicle movement restrictions through various channelization methods. Public and private access points also create conflicts for pedestrian, bicycle, transit and vehicle users, and those impacts should be assessed in the design process. The Green Book (AASHTO 2011a), the *TRB Access Management Manual* (TRB 2016a) and *NCHRP Report 659: Guide for the Geometric Design of Driveways* (Gattis et al. 2010) provide extensive guidance on access management and design.

4.1.6.3 Design Controls for Pedestrians and Bicyclists

On roadways with existing or anticipated high levels of pedestrian and bicycle usage, project design should provide appropriate roadside and bicycle facilities in the traveled way and/or roadside. These facilities must be coordinated with the other design elements in the traveled way and roadside, and they must be sensitive to project context. As a result, in some projects the design requirements for bicyclists and pedestrians may function as design controls that significantly influence the prioritization of design elements for all users of the right-of-way. For example, in some projects requirements for bicycle lanes may be considered a higher priority than a landscaped median, on-street parking or vehicle travel and turn lanes.

4.1.6.4 Design Controls for Freight and Transit Vehicles

Both freight and transit vehicles are classes of motorized design vehicles, but they can have significantly different operating characteristics in the right-of-way. Their specific needs and the impacts of design alternatives on their operation should be considered in the design process of multimodal roadways.

Freight vehicles typically are considered a part of the motorized traffic demand and generally do not receive special design accommodation beyond ensuring that basic roadway geometry—horizontal curves, lane widths and turning radii—are appropriate for the type and number of freight vehicles existing or anticipated. For a roadway designated as an official freight route, the project design should also ensure that the range of freight vehicles routinely expected can be effectively served.

Bus transit is the dominant form of public transportation in most urban and suburban areas. Most bus transit operates in mixed traffic on streets. Generally, designs that make traffic move faster and more safely will improve bus speeds and service reliability. Roadway geometry should be adequate for bus movement, and pedestrian access to transit stops should be convenient. Preferential treatment for transit (dedicated lanes, stations, and priority at traffic signals) may be desirable in some situations. In those cases, the benefits to transit riders should be balanced with

the effects on roadway traffic. Treatments and priorities for bus transit can vary depending on specific traffic, roadway and environmental conditions. Regardless of the type of treatment, the geometric design and traffic control features of a project should adequately and safely accommodate all expected vehicles.

Design guidelines, standards and practices for transit accommodation have evolved. Much recent guidance has addressed the needs and requirements of specific transit modes, such as buses, rapid transit and light rail transit (LRT). For example, the *Guide for the Geometric Design of Transit Facilities on Streets and Highways* (AASHTO 2014a) provides design practitioners with a single, comprehensive resource that documents and builds on past and present experience in transit design in streets and roadways.

As discussed throughout this Guide, the design of multimodal roadways emphasizes allocating the right-of-way to accommodate all modes in a reasonable manner. This allocation should be driven by consideration of modal priorities based on LOS and QOS, on performance metrics for each and all modes, and as defined by the surrounding context and community objectives. This approach should result in a well thought out and rationalized design trade-off process, the only method by which all of these factors can be appropriately understood, assessed and weighed against each other in a project's design.

4.1.7 Users with Disabilities in Multimodal Design

Pedestrian access routes should contain continuous and clear pedestrian pathways for individuals with mobility, visual, hearing or other disabilities. Many existing urban- and suburban-context roadways were originally designed primarily to serve motorized vehicles, and where pedestrian facilities have been provided or added, these facilities have not always been designed to accommodate pedestrians with a disability. If a roadway project does not provide the proper design of sidewalk widths, ramps, clearances, slopes, surfaces, streetscape furniture, traffic signals, street crossings and transit stops, the facility may be inaccessible to some disabled users. In those situations, the disabled users may have no options but to travel in vehicle travel lanes or directly adjacent to travel lanes with no physical separation, and either of these options is highly undesirable. Additional discussion of the history of and legal implications of accessible design within the public right-of-way is provided in Chapter 2 of this Guide.

The PROWAG (U.S. Access Board 2011) and a supplemental notice that addresses shared-use paths (U.S. Access Board 2013) provide guidance on accessible design. The PROWAG calls for a pedestrian access route to provide a 4-ft. minimum continuous clear width, a maximum grade consistent with the road grade, a maximum 2-percent cross slope, and a “firm, stable, and slip-resistant” surface (U.S. Access Board 2011). These accessibility guidelines greatly influence the design strategies for all pedestrian facilities, including sidewalks, shared-use paths, street crossings, curb ramps, signals, street furniture, transit stations, on-street parking, loading zones and more. Key guidance from the PROWAG and other reference documents is presented in *Achieving Multimodal Networks: Applying Design Flexibility and Reducing Conflicts* (FHWA 2016a), and can be summarized as follows:

- **Sidewalks.** Sidewalks should provide a continuous circulation path and connect pedestrians to accessible elements, spaces, and facilities. Where narrower than 5 ft., a 5-by-5-ft. minimum passing space is required at 200-ft. maximum intervals (U.S. Access Board 2011, Advisory R302.4). To increase maneuverability, additional space should be provided at “turns or changes in direction, transit stops, recesses and alcoves, building entrances, and along curved or angled routes, particularly where the grade exceeds 5 percent” (36 CFR Part 1190, U.S. Access Board Advisory R302.3). The *Urban Street Design Guide* (NACTO 2013) is a good source for additional information on sidewalk access routes.

- **Curb ramps.** Curb ramps facilitate pedestrian access between sidewalks and street crossings, and between sidewalks and accessible on-street parking. Curb ramps may be perpendicular or parallel to the pedestrian access route, or a combination of both, with a maximum running slope of 8.3 percent. The PROWAG allows for different maximum cross slopes depending on the traffic control in place at the crossing (36 CFR Part 1190, U.S. Access Board Advisory R302.6). Ramps should align with pedestrian crossings; the use of apex curb ramps (i.e., diagonal ramps in the center of a corner radius) should normally be a last resort, as these ramps direct pedestrians into the middle of the intersection and away from the crosswalk.

Each curb ramp must include a landing/turning space for wheelchair maneuverability and a detectable warning surface to alert pedestrians with a visual disability that they are entering or exiting the roadway. Detectable warning surfaces must include truncated domes to provide tactile feedback and must exhibit visual contrast with adjacent surfaces (e.g., light on dark or dark on light). Detectable warning surfaces should be placed at the back of the curb, unless otherwise specified by PROWAG (36 CFR Part 1190, U.S. Access Board Advisory R305.2). Detectable warning surfaces are also needed at blended transitions (i.e., crossings with a running slope less than 5 percent), raised crossings, and at pedestrian crossing islands.

- **Street furniture.** Street furniture (benches, trash receptacles, bike racks, newspaper racks, etc.) should not be placed within the continuous pedestrian access route. Obstructions near the access route should be detectable by cane. Protruding objects, such as wall- or pole-mounted items, must be limited because they can be difficult to detect and avoid (36 CFR Part 1190, U.S. Access Board Advisory R402).
- **Street crossings.** Street crossings continue pedestrian access route across travel lanes at intersections and mid-block locations. According to Section 3B.18 in the MUTCD (FHWA 2009b), a variety of striping designs may be used to denote the pedestrian crossing, but high-visibility ladder-style crosswalks with longitudinal lines are recommended due to their improved visibility. The roadway design should ensure that adequate roadway sight distance is available in advance of the pedestrian crossing to provide the proper visibility for approaching motorists and bicyclists. Sight distance should be increased as vehicle operating speeds increase.
- **Intersections.** Intersections are special design situations and additional treatments should be considered that minimize multimodal conflicts by reducing motorist turning speeds and improving motorist yielding rates. Curb extensions are able to shorten traveled way crossing distances, prevent illegal stopping/parking in close proximity of the crosswalk, and further increase visibility of pedestrians to motorists, particularly on roadways with on-street parking. Raised crossings enhance visibility and provide an additional traffic-calming benefit to encourage motorist yielding behavior. Pedestrian refuge islands break up long mid-block crossings and help pedestrians address directional conflicts one at a time.
- **Signals.** At signalized intersections, accessible pedestrian signals communicate the location of the pedestrian actuator (usually a pushbutton) and the direction and timing of “WALK” and “DON’T WALK” intervals in a non-visual format. Section 4E.09 in the MUTCD defines non-visual as one or more “audible tones, speech messages, and/or vibrating surfaces” (FHWA 2009b), whereas the PROWAG defines non-visual as both “audible tones and vibrotactile surfaces” (36 CFR Part 1190, U.S. Access Board Advisory R209). Section 4E.08 of the MUTCD advises that designers should separate pedestrian actuators by at least 10 ft. and locate each near a level landing or a blended transition to “make it obvious which pushbutton is associated with each crosswalk” (FHWA 2009b).

Section 4E.06 of the MUTCD recommends that walking speeds slower than 3.5 ft. per second be considered when determining pedestrian clearance times to accommodate older pedestrians and pedestrians with disabilities (FHWA 2009b). Signal timing should allow pedestrians to cross both sides of the street during a single cycle. Designers should place an ADA-compliant actuator at pedestrian crossing refuge islands for slower moving pedestrians to call the signal if they cannot cross the street in a single cycle.

- **Surface treatments.** The PROWAG requires planar and smooth pedestrian access route surfaces. Uneven unit pavers, rough bricks, and hand-tooled concrete control joints cause uncomfortable or even painful vibrations for people using wheeled mobility devices. Efforts should be taken to minimize vertical discontinuities between unit pavers, vault frames, gratings and points where materials intersect. Refer to the PROWAG and U.S. Access Board Advisory R302.7 for specifications for vertical discontinuities and horizontal openings. Saw-cut concrete control joints and wire-cut bricks are design methods to help reduce vibrations.

4.1.8 Aging Users in Multimodal Design

The proportion of U.S. drivers aged 65 years and over is expected to increase significantly in coming years. This means that a steadily increasing proportion of drivers and pedestrians will experience declining vision; slowed decision-making and reaction times; exaggerated difficulty when dividing attention between traffic demands and other important cognitive tasks; and reductions in strength, flexibility and general fitness. Although the effects of aging on people as drivers and pedestrians are highly individual, design practices that explicitly recognize these overall changes will better serve this growing segment of the nation's population.

The *Older Driver Highway Design Handbook*, first published in 1998, focuses exclusively on older drivers (FHWA 1998). Subsequent editions in 2001 and 2014 expand the handbook's focus to older drivers and pedestrians. The current reference, *Highway Design Handbook for Older Drivers and Pedestrians* (FHWA 2014d), provides designers and practitioners with a practical information source that links aging road user performance to highway design, operational and traffic engineering features. This FHWA handbook supplements existing standards and guidelines in the areas of highway geometry, operations and traffic control devices. Guidance priority in the handbook focuses on the intersection environment, reflecting aging drivers' most serious and persistent crash problem area, as well as the greatest exposure to risk for aging pedestrians.

Planning Complete Streets for an Aging America is another resource available to the design practitioner (Lynott et al. 2009). It provides project planning, design and operations guidance to address the special needs of aging users of the right-of-way in several specific areas including:

- Approaches to roadway design and engineering for older users,
- Best practices for making streets work better for older travelers, and
- Key design elements for older driver and pedestrian safety.

Another design guidance resource is the website maintained by ChORUS (Clearinghouse for Older Road User Safety) at <https://www.roadsafeseniors.org/>. A collaborative project involving the Roadway Safety Foundation and supported by the FHWA and NHTSA, the goal of ChORUS is to help communities improve conditions and safety for older road users by providing information on proven and cost-effective design features and crash countermeasures addressing older user needs, such as:

- Retroreflective signage that helps older drivers navigate at night,
- High-visibility crosswalks that allow drivers to more easily see pedestrians,
- Specialized pedestrian signal operations, and
- Left-turn lanes that improve sight distance at intersections and help prevent right-angle crashes.

ChORUS has been developed to provide quick and easy access to design guidelines for the aging population, technical documents, case studies and success stories, and information about innovative financing solutions.

4.2 Traveled Way Design Element Guidelines for All Users

This section of the Guide provides principles and guidance for the design of a roadway's traveled way with multiple users in low- and intermediate-speed environments. On roadways with shoulders and curbs, or shoulders in lieu of curbs, the traveled way as defined also includes the shoulders. Design elements of the traveled way include mid-block crosswalks and mid-block bus stops. The guidance in this chapter is intended to be used in conjunction with the guidance for the roadside in Chapter 5.

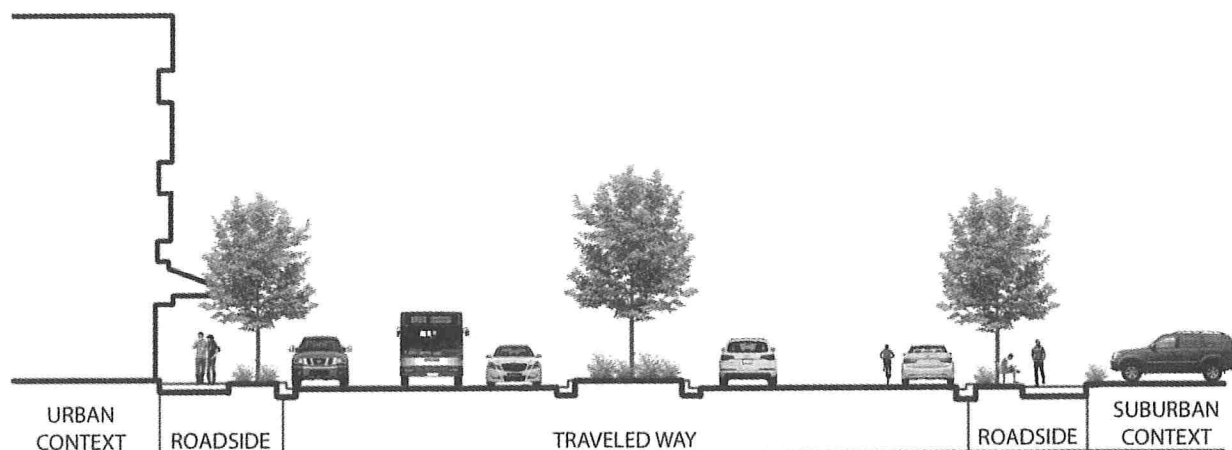
The traveled way is made up of the central portion of the roadway, as seen in Exhibit 4-6. It contains the design elements that allow for the movement of vehicles, transit, freight and often bicycles. The traveled way also is where vehicles interact with the roadside through on-street parking and access driveways. Design of the traveled way and roadside is influenced by the adjacent land use context. Exhibit 4-6 shows a typical urban context with building frontages at or near the back of right-of-way.

Fundamental design principles for the traveled way include development of a cross section that remains relatively uniform along the length of the roadway and its improvement projects. Traveled way design also incorporates the cross section transitions that result from removing or adding lanes, moving vehicles laterally through lane shifts, and changes in design elements or dimensions.

This section of Chapter 4 addresses considerations in cross section development, then discusses the following key design elements for the roadway traveled way:

- Vehicle travel lane widths,
- Curbs and shoulders,
- Bicycle facilities,
- Transit facilities,
- Medians and median landscaping,
- Parking configuration and width,
- Geometric transition design,
- Mid-block pedestrian/bicycle crossings, and
- Pedestrian/bicycle refuge islands.

Exhibit 4-6. Components of a typical urban/suburban street.



4.2.1 Traveled Way Cross Section Considerations

The goal of traveled way cross section development is to provide an objective and balanced assessment of the impacts, trade-offs and benefits of each alternative on each user mode using the traveled way. These include users that travel along the roadway, users who must cross the roadway (e.g., vehicles, pedestrians and bicyclists) and users that enter or exit the traveled way by access points such as intersections and driveways. This evaluation process requires careful consideration of the project's overall purpose and need, community goals and preferred performance outcomes for all users. In this Guide, Chapter 3 discusses the process of determining and balancing user service levels and Chapter 5 provides design guidance for the roadside portion of the traveled way. The design of multimodal traveled ways should consider not just multimodal transportation objectives, but other community and environmental objectives as well.

4.2.1.1 Consider All Cross Section Design Elements Concurrently

The designer always must keep in mind that, although the traveled way typically is the portion of the roadway with the highest total user volumes and speeds, it is but one portion of the overall roadway cross section. Design decisions in the traveled way often have significant impacts on users of the roadside as well as users of intersections. For projects that are scoped to include all these areas a trade-off analysis typically is required to balance all cross section design elements across all three design realms.

For some projects, preferred project outcomes and context considerations may place more emphasis on roadside user accommodation than the primary users of the traveled way (typically motorized vehicles). For example, the *road diet* concept removes one or more vehicle travel lanes from the cross section so that the right-of-way may be reallocated to other cross section priorities such as bicycle lanes, center turn lanes, on-street parking, medians, wider sidewalks, landscaping or other priorities. A specific discussion of the road diet concept is presented in another section of this chapter.

Evaluating cross section alternatives should include a comprehensive analysis of applicable issues and options using selected criteria (e.g., modal capacity; modal accessibility; geometric alignment; design concept; costs; right-of-way; environmental, social and economic impacts; operations; safety and so forth). Ideally, the selection of a preferred cross section alternative will be a consensus-based process involving all project stakeholders. The design process should include a process for selecting, refining and building consensus on cross section alternatives. A successful selection of a preferred alternative is one that is compatible with the context(s), reflects the prioritized needs of all users and best achieves the performance objectives and vision established for the corridor.

4.2.1.2 Cross Sections: Variations and Transitions Within Project Limits

Many roadway design projects pass through more than one context zone or involve variations within a context zone. This situation can occur even when the roadway functional classification of a roadway (arterial, collector or local) does not change within the project limits. These variations in context zones or features will typically suggest application of different design elements, criteria and cross sections that best align with those context situations.

Changes in context zone and features can indicate that the presence, needs and priorities of roadway user modes may also change along the project limits. For example, a rural arterial roadway that passes through a small village or town often will experience several transitions: from a fully rural context on the approach to the town/village to a town/village-edge context with increasing amounts of developed property and land use density, and to a town/village center environment with intersecting city streets and increases in building density with little or no

setbacks from the right-of-way line. These context changes usually indicate increasing numbers of non-motorized users traveling along and across the roadway, a need for pedestrian sidewalks and ADA-compliant ramps, turn lane additions to serve an increased number of driveway and intersection turning movements, a possible change from shoulders to curb and gutter, potentially on-street parking, and traffic control changes such as traffic signals and lower speed limits.

Significant adjustments to the traveled way, roadside and intersection designs may be needed to best serve the changing user and context conditions at transition locations. Traveled way transitions may require the provision of a smooth taper of appropriate length where lanes or shoulders change width, lanes diverge or merge, or lanes have been added or dropped. In multimodal roadway design, however, transitions extend beyond the traveled way geometric design requirements to reflect changes in context and multimodal activity. Transition locations also can be designed to provide visual, operational and environmental cues of upcoming changes in:

- Functional emphasis (e.g., from vehicle-oriented to pedestrian- and/or bicycle-oriented);
- Context (e.g., between a rural highway and a rural town context);
- Roadway type, particularly where functional classification and speed changes; and
- Width of roadway (e.g., narrowing or widening of lanes, use of raised medians or decreases or increases in the number of lanes).

Considerations for designing effective transitions include:

- Using the established guidance such as the MUTCD and the Green Book to properly design, mark and sign geometric transitions; and
- Designing transitions on a tangent section of roadway, avoiding areas with horizontal and vertical sight distance constraints.

If the traveled way transition is intended to correspond to a context change, community district change or speed zone change, the transition design principles may need to include:

- Providing a transition speed zone.
- Providing visual cues to changes in context or environment. Techniques may include changing traveled way features (e.g., raised medians, curb extensions, on-street parking and/or alternative pavements), roadside features (e.g., landscaping, street furniture, and/or street lighting) and intersection features (e.g., alternative pavements, raised intersections and/or enhanced crosswalks).
- Changing the overall traveled way width to better align with the context, roadway type and traffic characteristics. Approaches to adjusting the traveled way width can include reducing vehicle through and/or turn lanes, reducing lane widths and installing curb extensions at intersections and mid-block pedestrian crossings.

4.2.2 Curbs and Shoulders

On low- to moderate-speed roads, designers may choose to place shoulders, curbs, or sometimes a combination of both, on the outside of the traveled way.

In urban and suburban contexts, most roadways are planned to have curbs and gutters at the edge of the traveled way. Curbs and gutters serve to:

- Delineate the roadway edge,
- Protect the pavement edge,
- Facilitate roadway drainage,
- Assist in managing driveway access, and
- Provide some level of separation between vehicles and sidewalks, bikeways, roadside appurtenances and adjacent properties.

Whether paved or gravel, roadway shoulders typically are associated with rural highway and road classifications, and in some low-density suburban areas where open drainage facilities are preferred over closed drainage underground systems. Paved shoulders like those generally used for higher volume and higher-speed facilities are not generally used for low-speed urban and suburban contexts. On higher-speed facilities, shoulders provide

- Space for drivers to perform evasive maneuvers or to recover when drifting from travel lanes,
- Storage for stopped or broken-down vehicles,
- Locations for emergency vehicles to stay out of the traveled way,
- Areas for traffic enforcement activities, and
- More room for maintenance activities.

Curbs serve different purposes from shoulders, and the choice of which to use depends on the designer's priorities for the road based on consideration of how the road will be used and who will be using it. Paved shoulders significantly reduce maintenance costs and are proven to reduce crashes. With or without curbs, paved shoulders also can provide space for low levels of pedestrian and bicycle travel, which facilitates safer passing behaviors and improves comfort for all users. Shoulders are not suggested by the Green Book for urban areas, and most roadways in those contexts are built using curbed (or closed) cross sections, especially where right-of-way is limited. All users should be considered to develop the most appropriate design given the intended use of the shoulder.

Some designers choose to include a curb on the outside edge of a shoulder. Curbs also are frequently used along raised medians and islands on the inside of the traveled way in urban and suburban contexts. Designers have flexibility in determining when to use curbs and gutters on a roadway and when to pave shoulders, as well as designing shoulder widths and placement of rumble strips on higher-speed facilities.

4.2.2.1 *Current AASHTO Policy and Guidance*

The Green Book notes the frequent use of curbs on all types of low-speed urban roadways to control drainage, provide protection for pedestrians and, in general, allow greater flexibility in how the available roadway width can be used. Curbs may be placed at the edge of the traveled way on low-speed streets, but an offset of 1 ft. to 2 ft. is preferred (AASHTO 2011a).

Curbs can be designed with vertical or sloping faces. A curb and gutter section may be part of a longitudinal drainage system. Curbs used on the outside of a shoulder can help with drainage, reduce roadside erosion and control access.

Vertical curbs, generally 6 in. to 8 in. tall, are used to discourage drivers from leaving the roadway. Vertical curbs should not be used on high-speed roadways because an errant vehicle that strikes the curb may become airborne and overturn. Vertical curves can provide some measure of comfort to pedestrians using sidewalks adjacent to the roadway because vehicles tend to shy away from them. Sloping curbs, which generally are 4 in. tall or lower, are designed to be mountable by emergency or other vehicles when needed (ITE 2009a).

Generally, curbs used to delineate channelizing islands or medians should be offset at least 1 ft. to 2 ft. from the edge of the traveled way. Vertical curbs used intermittently along a roadway should be offset by at least 2 ft. according to the Green Book (AASHTO 2011a).

Care should be taken when curbs are used in conjunction with traffic barriers, such as on bridges. In those applications, vertical curbs should not exceed 4 in. in height. Sloping curbs are preferred and should be located flush with or behind the face of the barrier. If curbs are improperly located, vehicles can strike them and become airborne, either striking the barrier and overturning or vaulting over it. Curbs should not be used with concrete median barriers.

The Pedestrian Facilities Guide (AASHTO 2004b) emphasizes the role a curb can play in improving comfort and safety for pedestrians. It points out that curbs provide a clear delineation between the space intended for motorized vehicles and the space intended for pedestrian use. When pedestrian facilities are located adjacent to the roadway, or with only a narrow buffer strip separating them from the roadway, vertical curbs are preferred over sloping curbs because they do more to deter motorized vehicles from crossing them. Curbs along pedestrian facilities should discourage drivers from parking on sidewalks because this blocks the pedestrian route and could compromise pedestrian safety.

The Green Book states that shoulders are desirable on any roadway and that “paved shoulders’ advantages include providing a space for pedestrian and bicycle use, for bus stops, for occasional encroachment of vehicles, for mail delivery vehicles, and for the detouring of traffic during construction” (AASHTO 2011a). It recommends further that shoulders be 2 ft. to 8 ft. wide on urban arterials and collectors where sufficient right-of-way width exists. A minimum shoulder width of 4 ft. clear of rumble strips is recommended when the shoulder will be used to accommodate pedestrians and bicyclists. The Green Book does not provide minimum shoulder-width recommendations for local streets

The AASHTO Bicycle Guide states that paved shoulders are a good way to accommodate bicyclists, especially on roads with higher traffic volumes. The Bicycle Guide states, “Adding or improving paved shoulders can greatly improve bicyclist accommodation on roadways with higher speeds or traffic volumes, as well as benefit motorists. . . . Creating shoulders or bike lanes on roadways can improve pedestrian conditions as well by providing a buffer between the sidewalk and the roadway” (AASHTO 2014b).

Where bicyclists are expected to use a shoulder that has no curb or vertical obstruction, the shoulder should be at least 4 ft. wide and continuous along the length of the roadway and through intersections. Where a curb or other roadside barrier is present, the shoulder should be at least 5 ft. wide to accommodate a “shy” distance. Wider shoulders may be desirable where bicycle volumes are high or vehicle operating speeds are greater than 50 mph. Designers may wish to use the bicycle level of service (BLOS) model in the AASHTO Bicycle Guide, which includes factors for vehicle speeds, traffic volumes and lane widths to determine the appropriate shoulder width.

4.2.2.2 Principles and Considerations Regarding Use of Curbs and Shoulders

Shoulders may provide safety and operational benefits for all users by providing space for emergency, maintenance, or broken-down vehicles to stop outside of the traveled way, and by providing a space for pedestrians and bicyclists to travel outside of the space used by motorized vehicles. Considerations for the use of curbs and shoulders on low- to intermediate-speed roads include the following:

- Curbs can be used to encourage vehicles to remain within the traveled way and can provide comfort and protection to pedestrians using adjacent sidewalks. They can also be used in conjunction with a gutter pan to assist with roadway drainage. Curbs should only be used on roadways with low to intermediate speeds.
- Gutters, shoulder or edge-line rumble strips, and pavement markers can be obstacles to a bicyclist using the shoulder. The shoulder width provided for cyclists should be clear of these features. Therefore, shoulders may need to be wider to accommodate space for cyclists along with other desired traffic control and design features.
- Where unpaved drives or roads meet paved shoulders used by bicyclists, it is desirable for the drive or road to be paved for some portion of the approach to the shoulder. Where practical, the paved section should be sloped away from the roadway to help prevent gravel or other loose roadway materials from spilling onto the shoulder and impeding bicycle travel.

- Most shoulders are not considered pedestrian facilities because they are not intended for use by pedestrians; however, an occasional pedestrian may use the shoulder when necessary (e.g., when a vehicle breaks down). If a paved shoulder is intended to serve as a pedestrian facility, it should be considered a pedestrian access route and designed to meet accessibility requirements.
- Walking-along-roadway crashes occur when pedestrians who are walking along the travel lanes or shoulder of a roadway are struck by vehicles traveling on the roadway. Most of these types of crashes occur where sidewalks are not present. Adding paved shoulders to a roadway where pedestrians walk along a grass shoulder might not improve pedestrian safety because the paved shoulder may attract pedestrians closer to the travel lanes; however, widening existing paved shoulders has been shown to reduce walking-along-roadway crashes (FHWA 2001a).

4.2.2.3 *Use of Traveled Way Shoulders for Pedestrian and Bicycle Use*

The U.S.DOT defines a walkway as a continuous way designated for pedestrians and separated from motorized vehicle traffic by a space or barrier. U.S.DOT also notes that a traveled way shoulder provides a gravel or paved highway area for pedestrians to walk next to the roadway, particularly in rural areas where sidewalks and pathways are not feasible. Except where expressly prohibited, pedestrians may legally walk on roadway shoulders. Most highway shoulders are not intended for use by pedestrians, but they can accommodate occasional pedestrian use. If a shoulder is intended for use as a pedestrian access route “it must meet ADA requirements for pedestrian walkways to the maximum extent possible” (AASHTO 2004b). For more information, refer to the design topic on “Accessibility.”

When accommodation of pedestrian travel is needed, separate roadside pedestrian sidewalk or path facilities should be provided. While traveled way shoulders are not substitutes for a well-designed pedestrian facility, there may occasionally be a need to design shoulders as walkways where roadside facilities are not provided and space is constrained. U.S.DOT encourages all state and local agencies to consider providing and maintaining paved shoulders or walkways along both sides of streets and highways in urbanized areas, particularly near school zones and transit locations, and where there is frequent pedestrian activity (FHWA 2008).

4.2.2.4 *Recommended Practice*

The design and use of curbs and shoulders is highly situation-specific. Ideally, the design process will include the consideration of available right-of-way, likely roadway users and intended uses, travel speeds and aesthetics. However, the following guidelines can be applied to most multimodal roadways in low- and intermediate-speed contexts:

- Vertical curbs should be used when pedestrian facilities are adjacent to the roadway or separated from the roadway only by a narrow planted strip, as long as the roadway design speed is 45 mph or lower.
- Where shoulders are used to accommodate bicyclists, at least 4 ft. of shoulder width that is clear of rumble strips, raised pavement markers and gutter pans should be provided.
- Even where a gutter pan is not used, the presence of a curb should increase shoulder width by 1 ft.
- Pavement resurfacing offers an opportunity to reallocate roadway space. In some cases, designers should consider reducing lane widths to provide more paved shoulder width suitable for bicyclists. For example, in a retrofit situation, the AASHTO Bicycle Guide suggests that a 10-ft. or 11-ft. travel lane with a 3-ft. or 4-ft. shoulder for bicyclists is preferable to a 12-ft. travel lane with a 2-ft. shoulder (AASHTO 2014b).
- Including paved shoulders in the design of new and reconstructed roadways is cost effective and should be considered on rural and suburban arterial roadway projects. This affords the

best opportunity to get a 4-ft. or greater paved shoulder in place. This is also the time to consider other treatments (e.g., separated bike lanes, shared-use paths and sidewalks) that may be more desirable in urban and suburban contexts with higher bicycle and pedestrian demand.

4.2.2.5 Rumble Strips and Rumble Stripes

Center line rumble strips (CLRSs) and shoulder rumble strips (SRSs) are FHWA-proven safety countermeasures for reducing roadway departure crashes, including head-on and run-off-road crashes. A rumble strip becomes a “rumble stripe” when an edge line or center line pavement marking is placed on it.

Designers have flexibility regarding the placement and configuration of roadway rumble strips. Therefore, it is important that rumble strips be designed with bicyclist safety in mind. The AASHTO Bicycle Guide recommends providing a 4-ft. clear space from the rumble strip to the outside edge of a paved shoulder, or a 5-ft. clear space to an adjacent curb, guardrail or other obstacle (AASHTO 2014b). A reduced-length rumble strip measured perpendicular to the roadway or edge-line rumble strips (sometimes called rumble stripes) can be considered to provide additional shoulder width for bicyclists. The AASHTO Bicycle Guide recommends providing 12-ft. minimum gaps in rumble strips spaced every 40–60 ft. to allow bicyclists to enter or exit the shoulder as needed (AASHTO 2014b). Designers should consider longer gaps for contexts where bicyclists are traveling at relatively high speeds. Designers may also consider bicycle-tolerable rumble strips. Even though the strips can be made more tolerable, they are not considered rideable by bicyclists. Additional information on rumble strip and rumble stripe design can be found in the AASHTO Bicycle Guide, the *Decision Support Guide for the Installation of Shoulder and Center Line Rumble Strips on Non-Freeways* (FHWA 2001b), and the *State of the Practice for Shoulder and Center Line Rumble Strip Implementation on Non-Freeway Facilities* (FHWA 2017).

In constrained locations with a paved shoulder width less than 4 ft., designers should consider placing rumble strips at the far-right edge of the pavement to give bicyclists additional space near the edge of the lane. Results from *NCHRP Report 641: Guidance for the Design and Application of Shoulder and Centerline Rumble Strips* indicate that there may not be a practical difference in the effectiveness of rumble strips placed on the edge line or 2 ft. or more beyond the edge line on two-lane rural roads (Torbic et al. 2009).

4.2.3 Vehicle Travel Lane Widths

The criteria provided in the Green Book (AASHTO 2011a) describes design width values for through travel lanes, auxiliary lanes, ramps and turning roadways. There are also recommended widths for special-purpose lanes such as continuous two-way left-turn lanes. AASHTO also provides guidance for widening lanes through horizontal curves to provide for the off-tracking requirements of large trucks. Lane width in the Green Book does not include shoulders, curbs and on-street parking areas.

AASHTO notes that speed is a primary consideration when evaluating potential adverse impacts of lane width on safety on high-speed two-lane highways because drivers may have more difficulty staying within the travel lane. On any high-speed roadway, the primary safety concerns with reductions in lane width are crash types related to lane departure, including run-off-road crashes.

Conversely, the Green Book notes that in a reduced-speed urban environment, the effects of reduced lane widths are different and the design objective is often how to best distribute limited cross-sectional width to maximize safety for a wide variety of roadway users (AASHTO 2011a). Lane widths may be adjusted to incorporate other cross-sectional elements, such as medians for access control, bike lanes, on-street parking, wider sidewalks, transit stops, and landscaping. The

recommended ranges for lane width in the urban, low-speed environment (less than 50 mph) normally provide adequate flexibility to achieve a desirable urban cross section without requiring a design exception. Although 12-ft. lanes have been used historically for vehicle travel lanes, the Green Book notes that 10-ft. travel lanes are acceptable in low-speed (45 mph or lower) environments (AASHTO 2011a).

The Green Book's guidelines for different types of vehicle travel lane widths are provided by roadway functional classification. Those guidelines for low- and intermediate-speed roadway contexts are summarized in Exhibit 4-7.

4.2.3.1 Recommended Practice

Design decisions for lane widths are influenced by a wide range of factors, including:

- Type of travel lane (through, left or right auxiliary, two-way left turn);
- Functional classification of the facility;
- Travel demand;
- Actual and desired operating speed of the facility;
- Adjacent facilities in the right-of-way (e.g., medians, bicycle lanes, parking lanes, transit lanes);
- Presence and level of non-vehicle users; and
- Context of the surrounding area.

Parking lanes and lanes incorporating transit operations are addressed in separate sections of this chapter.

Based on consideration of guidance in the Green Book and other source documents, the research team developed recommendations for lane widths for low- and intermediate-speed facilities across the range of land use contexts discussed in Chapter 3 of this Guide. The suggested lane widths are provided in Exhibit 4-8. These width recommendations serve as a starting point in the multimodal design process; many other considerations and factors (discussed later in this section) may suggest higher or lower dimensions. Decisions on lane width should be made by the knowledgeable design professional after having evaluated the trade-offs for various cross section alternatives.

4.2.3.2 Lane Width Selection: General Principles and Considerations

A wide range of potential considerations beyond those listed in Exhibit 4-8 may influence the selection of appropriate lane widths for a specific design project. This section discusses these

Exhibit 4-7. Green Book suggested lane widths for urban low- and intermediate-speed facilities.

Lane Type	All Classes	Local Urban Street		Urban Collector Street		Urban Arterial Street	
	Range	Minimum	Preferred	Minimum	Preferred	Minimum	Preferred
Through Lane	9–12 ft.	9 ft.	10–11 ft.	10 ft.	11–12 ft.	10 ft.	11–12 ft.
Through Lane (Industrial)	11–12 ft.	11 ft.	12 ft.	11 ft.	12 ft.	10 ft.	11–12 ft.
Left/Right Turn/Auxiliary Lane	10–12 ft.	9 ft.	10–12 ft.	10 ft.	11–12 ft.	10 ft.	11–12 ft.
Two-Way Left-Turn Lane	10–16 ft.	N/A	N/A	10 ft.	11–12 ft.	10 ft.	11–12 ft.

Source: AASHTO 2011a

Exhibit 4-8. Suggested lane widths for various context zones and speed ranges.

Context Zone	Lane Type	Suggested Lane Widths for Target Operating Speeds by Context Zone *					
		20 mph	25 mph	30 mph	35 mph	40 mph	45 mph
Urban Core	Through	10 ft.	10 ft.	10 ft.	10 ft.	N/A	N/A
	L/R Turn	9–10 ft.	9–10 ft.	9–10 ft.	10 ft.	N/A	N/A
	TWLTL	10 ft.	10 ft.	10 ft.	10 ft.	N/A	N/A
Urban	Through	10 ft.	10 ft.	10 ft.	10 ft.	10–11 ft.	10–11 ft.
	L/R Turn	9–10 ft.	9–10 ft.	9–10 ft.	10 ft.	10–11 ft.	10–11 ft.
	TWLTL	10 ft.	10 ft.	10 ft.	10 ft.	10–11 ft.	10–11 ft.
Suburban	Through	N/A	10 ft.	10 ft.	10–11 ft.	11–12 ft.	11–12 ft.
	L/R Turn	N/A	9–10 ft.	9–10 ft.	10–11 ft.	11–12 ft.	11–12 ft.
	TWLTL	N/A	10 ft.	10–11 ft.	10–11 ft.	10–11 ft.	11–12 ft.
Rural Town	Through	10 ft.	10 ft.	10–11 ft.	10–11 ft.	11–12 ft.	11–12 ft.
	L/R Turn	9–10 ft.	9–10 ft.	10–11 ft.	10–11 ft.	11–12 ft.	11–12 ft.
	TWLTL	10 ft.	10 ft.	10 ft.	10–11 ft.	10 ft.	10 ft.

- * 1. On low- and intermediate-speed facilities with a mix of users, the selected design speed and the desired operating speed are typically the same value, except on higher volume principal arterials where design speed may be 5 mph above the desired operating speed.
2. On roadways primarily serving industrial uses, minimum lane widths should be 11 ft.
3. On roadways with high percentages (>5%) of large trucks and buses, outside lane widths should be a minimum of 11 ft., including any usable gutter width.

potential considerations and provides design guidance for the various types of travel lanes used in low- and intermediate-speed environments.

Where streets are designed in areas with a significant level of existing or planned use by non-motorized users, excessive street width can create barriers for pedestrians and encourage higher vehicular operating speeds. Wide streets can reduce the level of pedestrian interchange that supports economic and community activity. Wide streets also discourage crossings for transit connections, and the overall width of the street can affect the building height-to-width ratio, a vertical spatial definition that is an important visual design component of many urban streets.

Although vehicle lane width is only part of the overall width of the street, it is often cited as the design element that most adversely affects the comfort, convenience and safety of pedestrian crossings. In fact, many factors affect pedestrian crossing safety and exposure, including the number of lanes, presence of pedestrian refuges, curb extensions, walking speed and conflicting traffic movements at intersections.

In establishing the most appropriate vehicle lane width for a particular low- or intermediate-speed facility, the designer should consider the needs, safety and operational impacts of alternative widths to all legal users of the roadway facility. Some key factors that will influence lane width selection on a specific facility will include:

- **Total traveled way width.** The width of the traveled way should be adequate to accommodate through and turning traffic lanes, medians, curbs and appropriate clearances from curb or barrier faces. The width of the traveled way affects users' perceptions of the speed and volume of the street. Wide streets with multiple travel lanes may be perceived as a barrier to crossing where frequent crossings are desired and encouraged. Wider lanes contribute to wider traveled ways and larger intersections, which create longer crossing distances for pedestrians and bicyclists, increased exposure time to vehicle traffic, and the need for longer traffic signal clearance intervals. The total number and width of travel lanes selected should be based on a

balance of community objectives, the street's role in the overall network and the existence or lack of parallel roadways across which traffic can be balanced.

- **Functional classification.** The Green Book states that “while the accommodation of bicyclists, pedestrians, and transit users is an important consideration in the planning and design of highways and streets, the functional classification of a highway or street is primarily based on motorized vehicle travel characteristics and the degree of access provided to adjacent properties” (AASHTO 2011a). Higher order classifications serving urban areas such as principal arterial, minor arterial and collector roadways often have multiple and even competing roles in the urban street system. The Green Book goes on to say that “even though many of the geometric design values could be determined without reference to the functional classification, the designer should keep in mind the overall purpose that the street or highway is intended to serve, as well as the context of the project area” (AASHTO 2011a). For these reasons, the designer must be able to fully consider and balance design criteria such as travel lane width in consideration of the mobility, safety and convenience of all modes and users in the design process of these functional classifications across a broad range of network contexts and community priorities.
- **Design and control vehicle.** As discussed in this chapter under “Design Controls for Multimodal Roadways,” lane widths should consider the selected design and control vehicles for a project. The safety and operational impacts of a selected lane width also should be evaluated against the various types and sizes of vehicles expected and the frequency with which they are expected to use the facility. Some practitioners will conservatively select the largest design vehicle that could use a thoroughfare (e.g., WB 50 to WB 67), regardless of the frequency, although that is typically not the most cost-effective design solution in low- and intermediate-speed settings. Selecting too large a design vehicle can lead to wider cross sections and intersections, creating negative impacts on other users, particularly crossing pedestrians and bicyclists. Context-sensitive design emphasizes an analytical approach in the selection of a design vehicle, including evaluation of the trade-offs involved in selecting one design vehicle over another.
- **Vehicle capacity.** Lane widths may affect vehicle capacity on some facilities. The HCM suggests that lanes narrower than 12 ft. reduce vehicle capacity and therefore vehicle LOS on higher-speed facilities (TRB 2016b); however, recent studies have shown these impacts to be minimal or non-existent on low- and intermediate-speed roadways in urban settings when lanes are at least 10-ft. wide (Potts, Harwood and Richard 2007; Rahman et al. 2017; Potts 2006).
- **Lateral clearance.** A wider lane width provides more lateral clearance between vehicles traveling in opposite directions on two-lane facilities or traveling in the same direction on four-lane facilities. It also provides for more clearance to on-street parked vehicles, vertical curbs in outside lanes or raised medians, and fixed objects that may exist behind either of those curbed spaces. Lateral clearance also can impact operating speeds, with research showing that vehicle operating speeds are generally decreased by smaller roadside lateral clearance distances (Dixon et al. 2008b).
- **Design speed.** Design speed is a critical input to the design process for many geometric elements, particularly on high-speed (>45 mph) facilities. For most of these elements, however, the relationship between the design speed and the actual operating speed of the roadway is weak or changes with the magnitude of the design speed. The relationships between lane widths and vehicle speed are complicated by many factors, including time of day, the amount of traffic present, and even the age of the driver. Within the low- to intermediate-speed range, it is generally recommended to use somewhat wider lane widths for higher design speeds (i.e., 40–45 mph) than for the lower design speeds (i.e., 20–35 mph).
- **Operating Speed.** General agreement exists among design and traffic engineers with urban and suburban geometric design and operations experience that operating speeds tend to decrease as lane widths decrease to dimensions that create discomfort for drivers and make side-by-side driving more difficult. Although no definitive research establishes the relationships between

these two variables, a study by Fitzpatrick et al. (2003) found that on suburban arterial straight sections away from a traffic signal, higher speeds should be expected with greater lane widths. The study identified several variables other than the posted speed limit that show some sign of influence on the operating speed on tangent sections. These variables include access density, median type, parking along the street and pedestrian activity level.

- **Vehicle safety.** With limited exceptions that may represent random effects, research studies have shown no effect of lane width on vehicle safety on urban and suburban roadways in low- and intermediate-speed settings. As a result, the chapter on urban and suburban arterials in the HSM does not include a CMF for lane width on urban and suburban arterials (AASHTO 2010). On low- and intermediate-speed facilities, the risk of lane-departure crashes is less, and the design objective usually becomes how to best distribute limited cross-sectional width to maximize safety for a wide variety of roadway users. With vehicle mixes that contain substantial numbers of large trucks or buses, however, safety considerations would generally suggest a wider curb lane to more safely accommodate those wider vehicles.
- **Pedestrian safety.** Many design professionals believe that, in general, pedestrian safety is improved as vehicle lane widths are reduced because the shorter traveled way crossing distances reduce exposure time to vehicles and because of the reduced vehicle speeds typically induced by the narrower lane widths.
- **Bicycle safety.** Bicyclists experience the same safety benefits as pedestrians when crossing narrower lane widths. An equally important, if not more important, consideration in the case of bicycles is the relationship of the travel lane to bicycle traffic either within the lane or adjacent to it. The AASHTO and NACTO bicycle guides (AASHTO 2014b and NACTO 2014) provide extensive guidance on the design of bicycle accommodation within the traveled way, including recommended widths for both shared vehicle-bicycle lanes and striped bicycle lanes placed between the travel lane and vertical curb. When a parking lane is present, these lane width relationships become even more sensitive, and painted buffer strips sometimes are added between the vehicle, bicycle and parking lanes.
- **Space for other facilities.** Using narrower lanes on urban and suburban arterials can provide space for incorporation of other features that are positive for operations and safety, including medians, turn lanes, separate or shared bicycle lanes, parking lanes, bicycle lane buffers, wider sidewalks, enhanced border landscaping and context amenities.

Other potential considerations in the evaluation and selection of lane widths include:

- Curb lane widths should be measured to the face of the curb unless the gutter and catch basin inlets do not accommodate bicycles and motorized vehicles. To preserve available width for the best use, however, inlets should be designed to safely accommodate bicycle and motorized vehicle travel.
- In most cases, as a part of a thoughtful, integrated design of suburban or urban arterials and collectors, travel lane widths between 10 ft. and 11 ft. do not negatively impact overall motorized vehicle safety or operations and have little, if any, measurable effect on vehicular capacity (Harwood 1990). The study found one exception where 10-ft.-wide travel lanes should be used with caution, which is on undivided four-lane arterial roadways (Harwood 1990).
- Lanes greater than 11 ft. generally should not be used on roadways with high levels of pedestrian and bicycle activity, as they may encourage higher speeds.
- Roadways designated as major truck or transit routes through urban areas may require the use of wider lane widths for specific lanes, with 11 ft. generally being the minimum width used.
- Where adjacent lanes are unequal in width, the outside lane should be the wider lane to accommodate large vehicles and bicyclists (but only where bicycle lanes are not practical), and to facilitate the turning radius of large vehicles.
- Using wide curb lanes for bicyclist accommodation is not considered an effective means of accommodating bicyclists in urban areas; normally, bike lanes or shoulders are preferred.

- Where wider curb lanes are required, the designer should consider balancing the total width of the traveled way by narrowing turn lanes or medians to maintain the same overall pedestrian crossing width.
- Additional lane width may be necessary for receiving lanes at turning locations with tight curves.
- As an alternative to providing wider lanes for an entire route, wider lanes can be considered along horizontal curves to accommodate vehicle off-tracking based on a selected design vehicle. The Green Book provides guidance on widening for vehicle off-tracking (AASHTO 2011a).
- Many fire districts require a minimum 20-ft. clear traveled way. This minimum usually can be achieved on urban roadways with two or more lanes without medians, but it may present challenges on streets with one travel lane in each direction separated by a median.
- The HSM's safety performance functions for low-speed streets are not sensitive to lane width (AASHTO 2010). Findings from the available research are mixed regarding the effects of narrow lanes on crashes on urban streets. In some cases, narrow lanes appear to reduce crash rates, but in other cases, narrow lanes appear to increase crashes and in other cases, a particular width has lower crash rates than wider or narrower widths. Whatever the lane width, the potential for vehicle crash rates should be evaluated with the safety of vulnerable users in mind.

4.2.4 Bicycle Lanes/Accommodations

Bicycle travel within the traveled way can be accommodated using several design approaches. Selecting the appropriate design can depend on many factors, including roadway classification, vehicle speeds, user volumes, available right-of-way width, cross section (curb, shoulder or no shoulder), modal network plans, community plans and context.

The width of the street and the speed and volume of adjacent traffic are typically the most critical factors in providing safe bicycle accommodation. If adequate facilities cannot be provided, then the safety of bicyclists, motorists and pedestrians may all be compromised. In urban and suburban areas, the designer also may need to coordinate bicycle facilities with on-street parking, increased levels of public street and driveway access, transit facilities and signalized intersections.

Bicycle travel should be part of the roadway design considerations for most low- and intermediate-speed urban and suburban roadways, and for many rural roadways as well. Bicyclists vary in their level of skill and confidence, trip purpose and preference for facility types; accordingly, their mobility needs can vary quite significantly. In urban and suburban areas, bicycle facilities should encompass a system of on- and off-street interconnected routes, paths and roadway facilities that provide for safe and efficient bicycle travel.

Not all urban and suburban roadways will include dedicated bicycle facilities. Except for high-speed freeways and other roadways where bicycling is specifically prohibited, bicyclists are normally permitted to use any street for travel, even if designated bicycle facilities are not provided. Design accommodations for bicycles typically are determined by a community or regional master bicycle plan to ensure overall connectivity, including selection of the best streets for implementation of varying levels of bicycle facility priorities. The absence of designation in a master bicycle plan does not exclude the roadway designer from considering the bicycle mode and providing bicycle facilities if bicycles are allowed and the need currently exists or will exist with future context and network conditions.

Bicycle accommodation in the traveled way typically occurs through the use of dedicated bicycle lanes, cycle tracks and separated bike lanes.

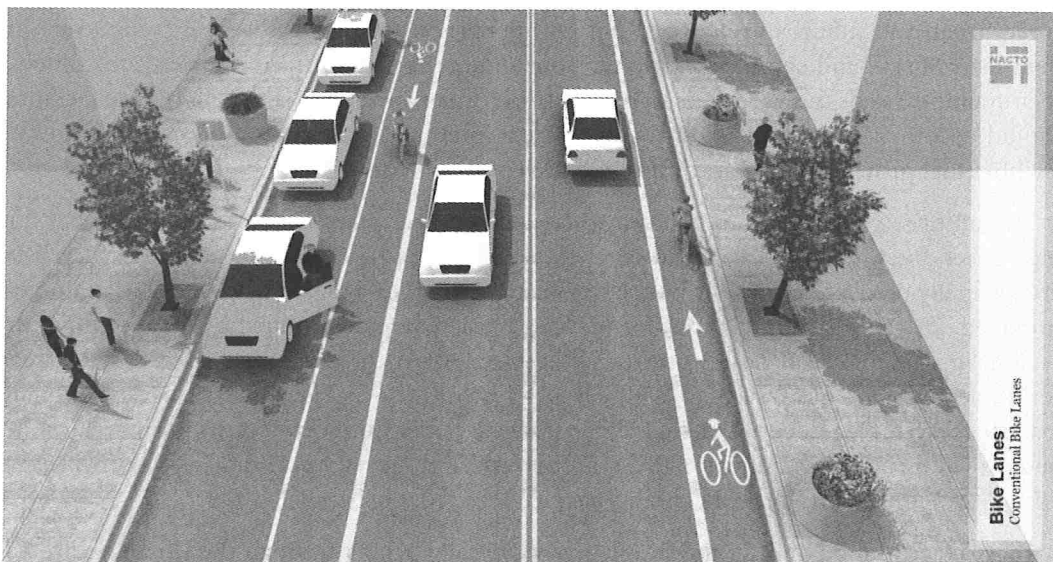
4.2.4.1 Bicycle Lanes

- **Conventional bike lanes.** Bike lanes designate a preferential space for bicyclists using pavement markings and signage (Exhibit 4-9). The bike lane is located adjacent to motorized vehicle travel lanes and flows in the same direction as motorized vehicle traffic. Typically, bike lanes are located on the right side of the street between the adjacent travel lane and curb, road edge, or parking lane. Bike lanes facilitate predictable behavior and movements between bicyclists and motorists.
- **Buffered bike lanes.** Buffered bike lanes are conventional bicycle lanes paired with a designated buffer space separating the bicycle lane from either the adjacent motorized vehicle travel lane and/or the parking lane (Exhibit 4-10). MUTCD guidelines allow for buffered bike lanes as buffered preferential lanes (FHWA 2009b). The buffering provides more space (“shy distance”) between the motorized vehicles and the bicyclists and allows bicyclists to pass other bicyclists without encroaching into the adjacent motorized vehicle travel lane.
- **Contra-flow bike lanes.** Contra-flow bike lanes are designed to allow bicyclists to ride in the opposite direction of motorized vehicle traffic (Exhibit 4-11). They convert a one-way traffic street into a two-way street with one direction used by motorized vehicles and bikes, and the other by bikes only. Contra-flow lanes are separated using yellow center-lane striping. This design introduces new design challenges and may introduce additional conflict points, as motorists may not expect oncoming bicyclists.
- **Left-side bike lanes.** Left-side bike lanes are conventional bike lanes placed on the left side of one-way streets or two-way median divided streets (Exhibit 4-12). Left-side bike lanes offer advantages along streets with heavy delivery or transit use, frequent parking turnover on the right side, or other potential conflicts that could be associated with right-side bicycle lanes. The reduced frequency of right-side door openings lowers dooring risk.

4.2.4.2 Separated Bike Lanes

A separated bike lane (or path) is an exclusive facility for bicyclists that is located within or directly adjacent to the traveled way and is physically separated from motorized vehicle traffic with a vertical design element. Separated bike lanes are differentiated from on-street bike lanes

Exhibit 4-9. Typical on-street bike lane.



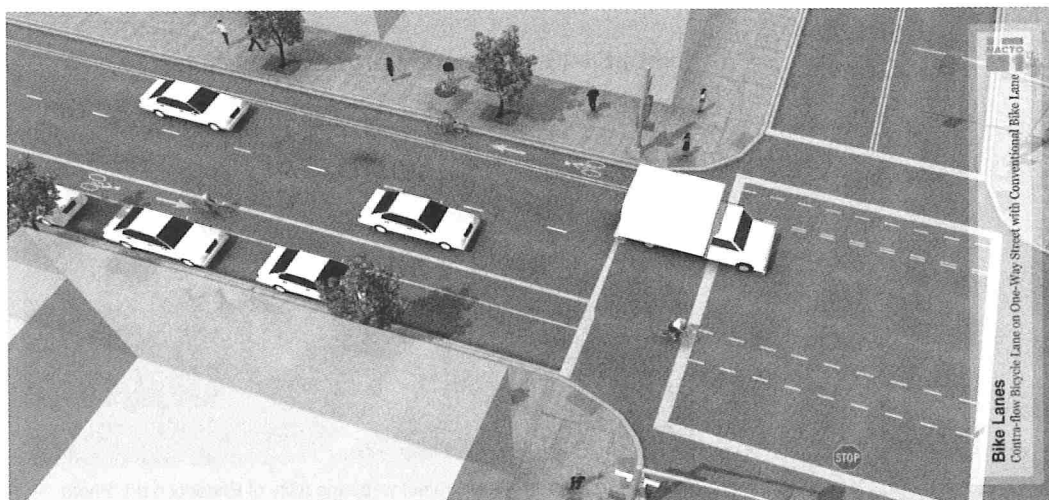
Source: NACTO (2014)

Exhibit 4-10. Typical on-street buffered bike lanes.



Source: NACTO (2014)

Exhibit 4-11. Typical contra-flow bike lane.



Source: NACTO (2014)

Exhibit 4-12. Typical left-side bike lane.

Source: NACTO (2014)

by the vertical element. They are differentiated from shared-use paths (and sidepaths) by being closer to the vehicle travel lanes and the fact that they are bicycle-only facilities. According to the *Separated Bike Lane Planning and Design Guide*, separated bike lanes are also sometimes called “cycle tracks” or “protected bike lanes” (FHWA 2015f).

- **Cycle tracks.** A cycle track is an exclusive bicycle facility that combines the user experience of a separated path with the on-street infrastructure of a conventional bike lane. A cycle track is physically separated from motor traffic and distinct from a pedestrian sidewalk. By separating cyclists from motor traffic, cycle tracks can offer a higher level of security than bike lanes and are attractive to a wider spectrum of the public.

Cycle tracks have different forms but all provide space intended for use exclusively or primarily by bicycles, and all are separated from motorized vehicle travel lanes, parking lanes and sidewalks. Where on-street parking is allowed, cycle tracks typically are located to the curbside of the parking area (in contrast to bicycle lanes). Cycle tracks may be one-way or two-way, and may be at street level, at sidewalk level or at an intermediate level.

- **One-way protected cycle tracks.** One-way protected cycle tracks are bikeways that are at street level and use a variety of physical methods for protection from passing traffic, as shown in Exhibit 4-13. A one-way protected cycle track may be combined with a parking lane or other

Exhibit 4-13. One-way protected cycle track.

Source: 3rd&5th Avenues project webpage (City of Phoenix n.d.). Photo © Small Giants, LLC. Used by permission.

Exhibit 4-14. Typical raised cycle track.

Source: NACTO (2014)

barrier between the cycle track and the motorized vehicle travel lane. This design reduces the risk of dooring compared to a bike lane, and it eliminates the risk of a doored bicyclist being run over by a motorized vehicle.

- **Raised cycle tracks.** Raised cycle tracks are bicycle facilities that are vertically separated from motorized vehicle traffic (Exhibit 4-14). Many raised cycle tracks are paired with a furnishings zone between the cycle track and motorized vehicle travel lane and/or pedestrian area. Raised cycle tracks may be at the level of the adjacent sidewalk or set at an intermediate level between the roadway and sidewalk to segregate the cycle track from the pedestrian area.
- **Two-way cycle tracks.** Two-way cycle tracks are physically separated cycle tracks that allow bicycle movement in both directions on one side of the road (Exhibit 4-15). A two-way cycle track may be configured as a protected cycle track at street level with a parking lane or other barrier between the cycle track and the motorized vehicle travel lane, and/or as a raised cycle track to provide vertical separation from the adjacent motorized vehicle lane.

Exhibit 4-15. Typical two-way cycle track.

Source: New York City DOT

4.2.4.3 Current AASHTO Policy and Guidance

- **Green Book.** The Green Book states, “. . . the designer should be familiar with bicycle dimensions, operating characteristics and needs” (AASHTO 2011a). It also references the existence of different types of bikeway facilities. The Green Book does not note recent design treatments (e.g., separated bike lanes) and provides little guidance on the type, selection or design of bicycle facilities; rather, it directs readers to the AASHTO Bicycle Guide (AASHTO 2014b) for appropriate design guidance for bicycle accommodation.
- **AASHTO Bicycle Guide.** The Bicycle Guide provides guidance on bicycle lanes, shared-use paths, bike trails and other related facilities. It does not specifically address separated bike lanes in the right-of-way because it was published prior to the widespread adoption of this facility type. The guide does provide design guidance regarding on-street bike lanes that may apply to separated bike lane designs, including a preferred bike lane width of 5 ft. to 7 ft. (1.5–2.1 m) and a desired 1 ft. (0.3 m) of additional width (shy distance) from vertical curbs and specifications for bicyclist operating dimensions (AASHTO 2014b).

The Bicycle Guide discourages a common configuration of separated bike lane designs where the bike lane is placed between the parking lane and the curb, stating that “such placement reduces visibility at driveways and intersections, increases conflicts with opening car doors, complicates maintenance, and prevents bike lane users from making convenient left turns” (AASHTO 2014b). Subsequent guidance featured in the FHWA *Separated Bike Lane Planning and Design Guide* (FHWA 2015f) provides design solutions to mitigate all of these concerns.

The Bicycle Guide also provides guidance on the design of sidepaths, a treatment with similar operational attributes to two-way separated bike lanes. The preferred width of sidepath facilities is 12 ft. (3.6 m), with a preferred minimum of 10 ft. (3.0 m). In constrained conditions, a sidepath may function in as little as 8 ft. (2.4 m). On this topic, the Bicycle Guide expresses caution about potential operational challenges, offering a list of specific conflicts that may apply to some two-way separated bike lane facilities (AASHTO 2014b). The guide concludes that one-way paths on both sides of the street, which may operate similarly to directional separated bike lanes, “can reduce some of the concerns associated with two-way sidepaths at driveways and intersections” (AASHTO 2014b, 5–11).

In addressing the design of shared-use paths, the Bicycle Guide recommends a minimum paved width for a two-directional shared-use path of 10 ft. (3.0 m), and in rare circumstances notes that a reduced width of 8 ft. (2.4 m) may be used. It recommends wider pathways, 11 ft. to 14 ft. (3.4 m to 4.2 m), in locations that are anticipated to serve a high percentage of pedestrians (30 percent or more of the total pathway volume) and higher user volumes (more than 300 total users in the peak hour) (AASHTO 2014b).

- **PROWAG.** To complement the design recommendations in the AASHTO Bicycle Guide, the U.S. Access Board supplemented its rulemaking on public rights-of-way in the PROWAG to also cover shared-use paths (U.S. Access Board 2013). The proposed rights-of-way guidelines, which address access to sidewalks, streets and other pedestrian facilities, provide requirements for pedestrian access routes, including specifications for route width, grade, cross slope, surfaces and other features. The Access Board proposes to apply these and other relevant requirements to shared-use paths and the supplementary rulemaking would add provisions tailored to shared-use paths into the rights-of-way guidelines (U.S. Access Board 2013).

4.2.4.4 Additional Guidance

- **Manual on Uniform Traffic Control Devices (MUTCD).** The MUTCD does not directly refer to separated bike lanes, but does describe a class of facilities called “preferential lanes” (FHWA 2009b). Preferential lanes are exclusive-use lanes for a particular vehicle type, and bicycle lanes are a recognized preferential lane type (MUTCD Section 3D-01). Preferential lanes may be barrier-separated from general-purpose travel lanes (MUTCD Section 3D.02). Application

of FHWA guidance related to barrier-separated preferential lanes formed the basis for the first separated bike lanes and has been expanded on in later FHWA guidance.

- **Separated Bike Lane Planning and Design Guide.** This FHWA design guide provides a comprehensive set of guidelines related to the preferred and minimum dimensions of separated bike lanes (FHWA 2015f). The guide stresses that “designing separated bike lanes is still evolving and until various configurations have been implemented and thoroughly evaluated on a consistent basis, design flexibility will remain a priority” (FHWA 2015f).

Separated bike lanes can be one-way directional facilities, generally traveling in the same direction as adjacent traffic, or two-way bidirectional facilities, offering two-way travel on one side of a street. The preferred clear travel width of a directional bike lane is 7 ft. (2.1 m), with a minimum width of 5 ft. (1.2 m). Total clear width between the curb and vertical buffer element should be at least the width of the fleet maintenance vehicle. Narrower separated bike lanes do not provide good opportunity for passing and may meet resistance from some bicyclists. The preferred clear travel width of a bidirectional separated bike lane is 12 ft. (3.6 m). No minimum width is specified in the FHWA guide.

The separation buffer dimensions may vary based on vertical buffer element type and on the presence of on-street parking. Adjacent to parking, the minimum buffer width is 3 ft. (0.9 m). Other vertical buffer types may function within as little as 1.5 ft. (0.45 m).

The *Separated Bike Lane Guide* describes eight forms of separation that can be used as vertical elements in the buffer area of the bike lane. The selected form of vertical separation is chosen based on the presence of on-street parking, overall street and buffer width, cost, durability, aesthetics, traffic speeds, emergency vehicle and service access and maintenance. (FHWA 2015f).

Exhibit 4-16 consolidates and summarizes the guidelines provided for widths of separated bike lanes in low- and intermediate-speed contexts.

4.2.5 Separated Bike Lanes: Principles and Considerations for All Users

FHWA states that bicycle “facilities should accommodate people of all ages and abilities” and encourages “transportation agencies to go beyond the minimum requirements, and proactively provide convenient, safe, and context-sensitive facilities that foster increased use by bicyclists” (FHWA n.d.a). Toward this goal, attributes of well-designed separated bike lanes include the following.

- **Adequate width.** Because the channelizing nature of separated bike lanes prevents operational flexibility for bicyclists to avoid hazards or pass slower bicyclists, separated bike lanes should be designed to allow two people to ride side-by-side and/or pass other users.

Exhibit 4-16. AASHTO/FHWA recommended separated bike lane widths.

Separated Bike Lane Area	Absolute Minimum Width	Preferred Minimum Width
Vertical Buffer Area*	1.5 ft. (0.45 m)	3 ft. (0.9 m)
One-way Clear Travel Area	5 ft. (1.5 m)	7 ft. (2.1 m)
Two-way Clear Travel Area	10 ft. (3.0 m)**	12 ft. (3.6 m)

*Minimum vertical buffer area widths vary in response to type of vertical buffer.

**Minimum two-way clear travel area widths here are based on AASHTO recommendations for sidepaths. In constrained conditions, an 8-ft. (2.4 m) minimum width may be appropriate.

Sources: AASHTO 2014b, FHWA 2015f

- **Forms of separation.** Separated bike lanes provide a physical separation from motorized vehicles by a curb, a raised median or a vertical element. The design of the separation should be based on the presence of on-street parking, overall street and buffer width, cost, durability, aesthetics, traffic speeds, emergency vehicle and service access, and maintenance. Generally, raised medians are preferred because they provide permanent curb separation; however, they are costly and may impact drainage, so raised medians are most commonly installed as part of full roadway reconstruction projects. Delineator posts or other lower-cost vertical elements can be ideal for retrofit projects where existing curb lines remain. Designers should consider the crashworthiness of separation types. Fixed objects in the roadway generally are not recommended and some movable objects, such as planters, may not be appropriate on higher-speed streets. According to the AASHTO Bicycle Guide, on lower-speed streets, separation types “need not be of size and strength to redirect errant motorists toward the roadway” (AASHTO 2014b, 5–11).
- **Bike lane elevation.** Separated bike lanes may be designed at any elevation between the street level and the sidewalk level. Many factors contribute to the selection of bike lane elevation, including drainage, accessibility, usable bike lane width, intersection frequency, curbside conflicts, maintenance and separation from pedestrians and motorized vehicles. Nonetheless, the final decision often is dictated by the construction technique (e.g., retrofit versus reconstruction). A separated bike lane elevation may transition throughout a corridor in response to changing conditions (e.g., raising to sidewalk level at driveways and lowering to street level at major intersections); however, designers should avoid frequent transitions to preserve a comfortable bicycling environment.
- **Visibility.** Clear sight lines should be provided between the roadway and the separated bike lane in advance of driveways and intersections.
- **Clear pedestrian interactions.** Additional width should be provided in the buffer area to accommodate pedestrian access to vehicles, commercial loading activity or an accessible aisle adjacent to accessible on-street parking spaces.
- **Maintenance.** The ability to maintain the separated bike lane free of debris is crucial to preserving the functionality of the facility. When building separated bike lanes, municipalities must consider how they will be swept and, if applicable, plowed during snow events. Designers should consider facility designs that provide a clear width compatible with maintenance equipment.

4.2.5.1 Recommended Practice

- **Design guidance.** Exhibit 4-17 provides recommended widths of separated bike lanes for low- and intermediate-speed streets in the urban contexts. These recommendations are based on FHWA and AASHTO guidelines, and have been adapted for this Guide to account for three levels of non-motorized multimodal accommodation.
- **Implementation guidance.** Separated bike lanes may be configured on the left side of one-way or median divided streets. Consider a left-side running separated bike lane on corridors with high-frequency transit routes, where there are fewer driveways, intersections or conflicts on the left side of the street, or where on-street parking is located on only the right side of the street. If accessible on-street parking is provided, an accessible aisle must be provided to allow users to access the sidewalk. The separated bike lane width may be reduced to accommodate the accessible aisle. Designers can consult the *Separated Bike Lane Guide* for common configurations (FHWA 2015f).
- **Small Town and Rural Multimodal Networks (FHWA 2016e).** This FHWA resource is intended for transportation practitioners in small towns and rural communities. It applies existing national design guidelines to a rural setting and highlights small town and rural case studies. The document addresses challenges specific to rural areas, recognizes how many rural

Exhibit 4-17. Recommended separated bike lane widths by multimodal priority level.

Multimodal User Priority Level *	Separated Bike Lane Zone	Width **
LOW Multimodal Priority	Vertical Buffer Area	1.5 to 3 ft. (0.45 – 0.9 m)
	One-Way Clear Travel Area	5 ft. (1.5 m)
	Two-Way Clear Travel Area	10 ft. (2.4–3.0 m) ***
MODERATE Multimodal Priority	Vertical Buffer Area	3–4 ft. (0.9–1.2 m)
	One-Way Clear Travel Area	7 ft. (2.1 m)
	Two-Way Clear Travel Area	10 ft. (3.0 m)
HIGH Multimodal Priority	Vertical Buffer Area	3.0–6.5 ft. (0.9–2.0 m)
	One-Way Clear Travel Area	10 ft. (3.0 m)
	Two-Way Clear Travel Area	12 ft. (3.6 m)

*Design and operating speeds should be commensurate with multimodal priority. Moderate and high multimodal priority designs should typically have design speeds of 35 mph and lower.

**Total clear width between the curb face and vertical element should be at least the fleet maintenance vehicle width. Clear widths narrower than 7 ft. (2.1) may require specialized equipment. (FHWA 2015e)

***In constrained conditions, an 8 ft. (2.4 m) minimum width may be appropriate.

Source: Adapted from information in AASHTO (2014b), FHWA (n.d.a) and FHWA (2015d)

roadways are operating today, and focuses on opportunities to make incremental improvements despite the geographic, fiscal and other challenges that many rural communities face. It provides information on maintaining accessibility and MUTCD compliance, while encouraging innovations such as “Yield Roadways” and “Advisory Shoulders” (dashed bicycle lanes). The document notes that, as of 2016, an approved Request to Experiment document is required to implement Advisory Shoulders (FHWA 2016e).

4.2.6 Transit Facilities

This section of the Guide identifies the key elements of transit facilities and operations that affect the design of roadways, and provides information on other resources that contain detailed design guidance for integrating roadway and transit design.

Many urban and suburban roadways accommodate public transportation, as do some rural roadways. The types of transit services accommodated on roadways range from local and express bus service in less dense urban areas to bus rapid transit (BRT), trolleys, streetcars and LRT. These transit services can be accommodated within a dedicated right-of-way, in the roadway right-of-way, or in mixed-flow lanes. In all cases, the design of the roadway needs to consider the special requirements of transit vehicles, running ways and operations, current and future plans, and pedestrian and bicycle access.

4.2.6.1 Types of Transit Operating in and Adjacent to Roadways

The various types of public transportation systems that use urban, suburban and rural roadways have differing physical and operating characteristics that will establish the design controls and geometric design parameters in roadway design. It is important for the roadway designer to understand the dimensions and capabilities of the type of transit that currently uses (or is

planned to use) the roadway, and how the transit vehicles, their operation and their stops and stations will affect the design of the roadway.

4.2.6.2 *Transit Facilities on Roadways*

Transit on urban roadways can utilize many operating configurations, including:

- Mixed-flow travel lanes;
- Transit or high-occupancy vehicle (HOV) lanes in the median or adjacent to mixed-flow lanes that are used for transit either full-time or during peak periods;
- Reversible or contra-flow dedicated transit lanes (in the median or in outside travel lanes);
- A dedicated and separated transit way in the median, inside travel lanes or outside travel lanes;
- A dedicated and separated transit way elevated on structures above the roadway; and
- Transit-only streets, busways, or transit malls.

Each operating configuration requires that the roadway designer understand the right-of-way requirements of the transit facilities and their interactions with traveled way lanes, intersections, pedestrian facilities and, where present, bicycle facilities. Safe and convenient access between transit vehicle stops and stations and their riders (generated by parking, pedestrian and bicycle facilities) is a critical element of designing for all users in transit environments. Transitways within roadways also affect the required roadway right-of-way width because transit systems can employ multiple lanes of sets of tracks.

Transit stops and stations can have multiple design requirements depending on required peak user demand at the stop/station, the transit vehicle loading/unloading operation, the frequency of service and other factors. Transit stops typically relate to bus operations and imply more modest passenger loading/unloading requirements that may range from a single bus stop sign to dedicated waiting areas with benches and shelters. Conversely, for fixed transit services such as trolleys and LRT systems, a transit station generally implies heavier loading/unloading volumes with more substantial passenger amenities such as much larger loading/unloading areas, ticketing facilities, restrooms or other services. Stations may accommodate multiple vehicles or have integrated intermodal facilities. The roadway designer needs to coordinate with the responsible transit agencies to identify the appropriate running way configuration, transitions, and the locations and design of stops and stations in and adjacent to the right-of-way.

4.2.6.3 *Consideration for Changing Transit Conditions*

When designing roadways that are identified as future transit corridors, the designer will need to consider several factors to reserve the appropriate right-of-way and ensure the design is relatively easily converted to accommodate transit and transit access. In addition to specific design issues, the practitioner may need to consider planning considerations such as:

- Changing transit types over time,
- Plans for changes in stop or station locations and spacing to meet changing context and future development, and
- Possible changes in transit routing.

4.2.6.4 *Transit Design Guidance*

The predominant transit facility type encountered in roadway design is the fixed-route bus transit stop. This Guide provides general design guidance and considerations for this most common design situation. The Guide does not present design guidance for other types of transit facilities or their integration into roadway facilities, although several excellent design guidance resources are discussed at the end of this section.

4.2.6.5 Bus Stop Design Considerations

The most typical transit facility accommodation in urban, suburban and some rural roadways is the bus stop. This section of the Guide presents general guidance for the planning and design of bus stops based on current national guidance. When designing a roadway project, the local transit agency also should be consulted to ensure the designer understands the transit agency's specific service needs and that those needs are addressed by the design solution.

4.2.6.6 General Principles and Considerations

Bus stop locations must address both traffic operations and passenger accessibility issues. If possible, the bus stop should be located in an area where typical amenities (e.g., benches or shelters) can be placed in the public right-of-way as needed. A bus stop location should always consider user access, potential ridership, traffic and rider safety and bus operations elements that may require site-specific evaluation. Well-lit, open spaces visible from the street create a safer environment for waiting passengers.

Designing Walkable Urban Thoroughfares (ITE 2010a) provides a thorough discussion of considerations in locating and designing bus stops that should be coordinated with other elements and functions of roadway design and operations. Those considerations include safety elements for drivers and transit users, and efficiency of bus operations. Key placement considerations include the following:

- The preferred location for bus stops is the near side or far side of an intersection, where pedestrian accessibility may be available from both sides of the street and the cross streets. Connections to intersecting bus routes also occur at intersections.
- Bus stops may be placed at a mid-block location on long blocks or to serve a major transit generator.
- At mid-block bus stop locations, crosswalks should be placed behind the bus stop so that passengers do not have to cross in front of the bus, where they are hidden from passing traffic.
- Bus stops should be placed to minimize the difficulties associated with lane changes and weaving maneuvers of approaching vehicles. Where it is not acceptable to stop the bus in traffic and a bus pullout is justified, a far-side or mid-block curbside stop is generally preferred.

4.2.6.7 Bus Stop Design

Bus stop design in the right-of-way should attempt to include the following minimum elements for passenger accessibility, safety and comfort (ITE 2010a and NCHRP Project 15-48 research team):

- In roadsides with a detached sidewalk (planting strip between curb and sidewalk), the design should:
 - Provide a landing area adjacent to the curb for a minimum distance of 34 ft. in length and a minimum of 8 ft. in depth (from face of curb);
 - For stops serving smaller buses, smaller landing areas may be acceptable; and
 - Provide a connecting pathway from pedestrian thoroughway to landing area.
- Provide convenient pedestrian pathways/access ways to and from adjacent buildings.
- Locate the bus stop so coach operators have a clear view of passengers and waiting passengers can see oncoming buses.
- Minimize driveways in and adjacent to the bus stop area.
- Locate street furniture more than 2.5-ft. tall in a way that provides motorists exiting nearby driveways clear visibility of the street.
- Passenger boarding areas should have a pad with a smooth, broom-finished surface to accommodate high heels and wheelchairs, and must have high-strength capacity to bear the weight of a shelter. For aesthetics, textured or decorative paver tiles can be used in combination with a concrete pad. The slope of the pad should match the slope of the adjacent sidewalk and allow drainage of the pad (2 percent maximum per PROWAG requirements).

- Use landscaping near the passenger boarding area to maximize passenger comfort, but place any landscaping far enough back from the curb face to prevent interference with bus or passenger visibility. All landscaping should be located so as not to obstruct the shelter canopy or obscure sight lines at the bus stop. Shade trees are desirable, and the preferred location is at the back of the sidewalk.
- Maintain at least 5 ft. of clearance between bus stop components and fire hydrants.
- Locate bus stops where there is a standard curb in good condition. Bus stops are designed with the assumption that the bus is the first step from the landing. Access to the bus is more difficult for elderly and mobility-impaired passengers if the curb is absent or damaged.
- Surround all street furniture by at least 4 ft. of horizontal clearance wherever possible for access and maintenance between components.
- Provide at least 10 ft. of clearance between the front edge of a pedestrian crosswalk and the front of a bus at a nearside bus stop, and 5 ft. between the back edge of a crosswalk and the rear of the bus at a far-side bus stop.
- Avoid placing a bus stop so that the bus wheels will cross over a catch basin as it pulls to the curb. Crossing a catch basin can cause the bus to lurch and possibly throw off passenger balance. Over time, bus operations at the stop also can contribute to excessive settlement of the catch basin's structure. To avoid splashing waiting passengers as the bus pulls to the curb in wet weather, consider draining away from the curb.
- Design for and place clear notifications of parking restrictions (either curb markings or NO PARKING signs) at bus zones. A lack of parking restrictions affects bus operations, traffic movement, safe sight distance and passenger access. For example, inadequate or poorly marked parking restrictions may lead to situations when buses are unable to use the curb and sidewalk to deploy its lift in order to board or alight wheelchair passengers.

4.2.6.8 Design Bus Vehicle

The bus is one of the design vehicles used in roadway design for urban roadways with transit routes. Some transit agencies use smaller, urban-scaled transit vehicles (e.g., 30-ft. to 32-ft. coaches), and use of vehicles with the smallest possible turning radii should be encouraged. Most fleets use standard coaches with the design specifications described in this section of the Guide. Critical dimensions of anticipated bus types should be identified, including their turning radii requirements. For a 40-ft. coach or a 60-ft. articulated bus, the minimum inside radius is 21 ft. to 26 ft. and the minimum outer radius is 44 ft. to 48 ft. Turning templates should be used in the design of facilities to identify the curb return radius and required pavement width to avoid vehicle encroachment into opposing travel lanes. Additional allowance should be made for any bicycle racks added to the front of the bus. Typically, the addition of a bicycle rack adds about 3 ft. to the length of the bus.

4.2.6.9 Bus Pullout Design in the Traveled Way

Bus pullouts (turnouts) are desirable only under selected conditions because of the delay created when the bus must reenter traffic. Bus turnouts are typically used only on roadways with higher operating speeds of 40 mph or higher.

Typical advantages and disadvantages of a bus pullout include the following (Kimley-Horn and Assoc. 2004):

Advantages

- Allows traffic to proceed around the bus, reducing delay for general traffic;
- Maximizes vehicular capacity of roads [particularly important on roadways that prioritize high-volume vehicle mobility];
- Clearly defines the bus stop;
- Passenger loading and unloading can be conducted in a more relaxed manner; and
- [Reduces] potential for rear-end crashes.

Disadvantages

- More difficult to reenter traffic, increasing bus delay and increasing average travel time for buses;
- Uses additional space and may require right-of-way acquisition.

Buses also may have difficulty pulling parallel to the curb, reducing accessibility, and they may face a greater crash risk pulling back into traffic from the pullout than buses stopped in the traffic lane.

4.2.6.10 Bus Pullout Placement and Design

Guidelines prepared for the transportation authority of Orange County, California, also provide the following information on bus pullout placement and design (Kimley-Horn and Assoc. 2004):

The far side of an intersection is the preferred location for warranted turnouts. Nearside turnouts typically should be avoided because of conflicts with right-turning vehicles, delays to transit service as buses attempt to reenter the travel lane, and obstruction of pedestrian activity as well as traffic control devices. The exception would be where buses would use a right-turn lane as a queue jump lane associated with a bus signal priority treatment at an intersection (where a far-side pullout is not possible). Turnouts in mid-block locations are not desirable unless associated with key pedestrian access to a major transit-oriented activity center and subject to the general warrants above.

The Orange County guidelines further recommend that pullouts (turnouts) should be placed at signalized intersections where the signal can create gaps in traffic allowing the bus to reenter the street. Twelve (12) ft. width is desirable to reduce sideswipe accidents; 10 ft. width is considered minimum. Where bike lanes are present, and where bus layovers occur, bus pullouts should be wide enough so that the buses do not impede the bike lanes (Kimley-Horn and Assoc. 2004). Typical urban bus pullouts are usually made up of an entrance taper (40 ft. to 60 ft.), stopping area (40 ft. to 60 ft. per each standard and articulated bus, respectively) and exit taper (40 ft. to 60 ft.).

4.2.6.11 Bus Stop Passenger Boarding Area

Passenger boarding areas should comply with PROWAG guidance:

- Door clearance: Minimum of 5 ft. wide (along the curb) by 8 ft. deep (from face of curb to back of boarding area);
- Distance between front and rear boarding area: 18 ft.;
- Surface material: Stable, firm and slip resistant;
- Slope: Does not exceed 1 ft. vertical over 20 ft. horizontal (5 percent);
- Cross slope: Does not exceed 1 ft. vertical over 50 ft. horizontal (2 percent);
- Clear throughway width: 48 in. maintained in boarding area; and
- Vertical clearance: 84 in. maintained in boarding area.

Additional local agency requirements for boarding areas may also need to be met.

4.2.6.12 Additional Transit Design Guidance for the Traveled Way

The following transit facility design guidance documents are available to assist the roadway designer in understanding more specific design and operations guidance for all types of transit accommodation in the traveled way, including operating characteristics, service efficiency, and many related design elements and criteria. Those documents include:

- **Guide for Geometric Design of Transit Facilities on Highways and Streets** (AASHTO 2014a). This comprehensive reference to current practice in the geometric design of transit facilities on streets and highways covers the following facilities:
 - Local buses, express buses and BRT operating in mixed traffic, bus lanes, and HOV lanes, and bus-only roads within street and freeway environments; and
 - Streetcars and LRT running in mixed traffic and transit lanes, and within medians along arterial roadways.

The guidelines are based on a review of relevant AASHTO, TRB, and ITE documents, and of design reports provided by various transit agencies.

- **This Guide.** Chapter 3 discusses the implications of basic vehicle characteristics on roadway design, summarizes basic roadway design requirements, and contains general capacity guidelines. The controls and guidelines apply to bus facilities operating on freeways, streets, and in separate rights-of-way. They also cover streetcar and light rail operations within street rights-of-way. Chapter 6 addresses pedestrian and bicycle access to transit. Riders must be able to reach bus stops or train stations comfortably, safely, and by the most direct routes. Access to stops and stations can be gained by walking, riding a bicycle, or taking a motorized vehicle (including a bus). Walking from adjacent land uses requires stops and stations to have safe, direct, and accessible pedestrian connections to the adjacent community. Cycling from the surrounding community requires stops and stations to be connected to appropriate bicycle facilities, and to have ample and secure bicycle parking. Chapter 6 outlines planning and design guidelines that achieve these objectives. It also contains some general guidelines for passenger amenities at stations and stops.
- **Transit Street Design Guide** (NACTO 2016). This guide from NACTO provides design guidance for the development of transit facilities on urban city streets, and for the design and engineering of city streets to prioritize transit, improve transit service quality and support other goals related to transit. Developed through a peer network of NACTO members and transit agency partners, it incorporates information from other design guidance, city case studies, best practices in urban environments, research and evaluation of existing designs, and professional consensus based on North American street design practice. Building on the *Urban Street Design Guide* (NACTO 2013) and *Urban Bikeway Design Guide* (NACTO 2014), the transit design guide details how reliable public transportation depends on a commitment to transit at every level of design.
- **TCRP Report 183: A Guidebook on Transit-Supportive Roadway Strategies** (Ryus et al. 2016). This report addresses ways to improve bus speed and reliability on surface streets while addressing the needs of roadway users that include motorists, bicyclists and pedestrians. The report “(1) identifies consistent and uniform strategies to improve transportation network efficiency to reduce delay and improve reliability for transit operations on roadways; (2) develops decision-making guidance for operational planning and functional design of transit/traffic operations on roads that provides information on warrants, costs, and impacts of strategies; (3) identifies the components of model institutional structures and intergovernmental agreements for successful implementation; and (4) identifies potential changes to the MUTCD and related documents to facilitate implementation of selected strategies” (Ryus et al. 2016).
- **TCRP Report 175: Guidebook on Pedestrian Crossings of Public Transit Rail Services** (Fitzpatrick et al. 2015b). Presenting an array of engineering treatments to improve the safety of pedestrians using light rail, commuter rail and streetcar services, this guidebook “presents pedestrian crossing issues associated with the National Environmental Policy Act of 1969 and the Americans with Disabilities Act; summarizes readily available decision flowcharts used to make decisions regarding pedestrian treatments at rail crossings; presents information for 34 pedestrian treatments used at rail crossings, grouped into eight appropriate categories; and includes four case studies that examine specific decisions with respect to pedestrian-rail crossings” (Fitzpatrick et al. 2015b). It is supplemented by the contractor’s final research report, *TCRP Web-Only Document 63: Treatments Used at Pedestrian Crossings of Public Transit Rail Services* (Fitzpatrick et al. 2015c).
- **TCRP Report 117: Design, Operation, and Safety of At-Grade Crossings of Exclusive Busways** (Eccles and Levinson 2007). Exclusive busways in separate rights-of-way may have at-grade crossings with roadways or pedestrian and bicycle facilities. *TCRP Report 117* provides guidelines for the safe design and operation of at-grade crossings of exclusive busways. The guidelines can assist transit, traffic engineering and highway design agencies in planning, designing, and operating

various kinds of busways through roadway intersections to enhance safety while maintaining efficient transit and highway operations and minimizing pedestrian delay. Guidance is included for at-grade intersections along busways within arterial street medians; physically separated, side-aligned busways; busways on separate rights-of-way; and bus-only ramps. Highway intersections, mid-block pedestrian crossings and bicycle crossings are discussed.

- **TCRP Report 112/NCHRP Report 562: Improving Pedestrian Safety at Unsignalized Crossings** (Fitzpatrick et al. 2006). The research team that developed this joint transit/highway report provides useful guidelines for selecting pedestrian crossing treatments for unsignalized intersections and mid-block locations. Based on key input variables (e.g., pedestrian volume, street crossing width and traffic volume), quantitative procedures presented in the report can be used to generate a recommended treatment from among four crossing treatment categories. The report also suggests potential revisions to the MUTCD pedestrian warrant for traffic control signals. Findings of the study include that the crossing treatment type affects motorist compliance and that factors influencing the effectiveness of a crossing treatment include the number of lanes being crossed and posted speed limit. Appendices to the report (some available online) provide useful information and tools for improving pedestrian safety at unsignalized crossings.
- **TCRP Report 19: Guidelines for the Location and Design of Bus Stops** (TTI et al. 1996). The primary objective of the research for this report was to develop guidelines for locating and designing bus stops in various operating environments. The guidelines presented will assist transit agencies, local governments, and other public bodies in locating and designing bus stops that consider bus patrons' convenience, safety and access to bus stop sites along with safe transit operations and traffic flow, and include checklists of factors that should be considered.

4.2.7 Medians

The median—the area of the roadway that separates opposing lanes of vehicle traffic—can vary significantly in width and purpose. A median can be open (with pavement markings only), depressed (e.g., with grass or landscaping) or channelized (e.g., raised medians or islands).

Operational and safety benefits of medians include limiting conflict points, reducing certain crash types (e.g., head-on collisions), providing pedestrian and bicycle crossing refuge, providing space for left-turning and crossing vehicles, storing plowed snow and collecting stormwater runoff. On low- and intermediate-speed roadways in urban and suburban contexts, medians typically are used to provide these same benefits, with added emphasis placed on landscaping, pedestrian and bicycle refuge, lighting and utilities. In urban and urban core contexts, fixed transit may operate in a median, and parking may also exist within or adjacent to medians.

In addition to the operational and safety functions of medians, well-designed and landscaped medians can help create tree canopies over travel lanes and serve as a focal point of the street or an identifiable gateway into a community, neighborhood or district.

Flexibility in the design of median width revolves around the median's function, appurtenances and landscaping to be accommodated in the median and available right-of-way. Designers need to consider trade-offs between the provision of a median and other design elements, particularly in constrained rights-of-way.

4.2.7.1 Multimodal Safety Considerations of Medians

Raised medians provide many benefits to all users of the roadway. These benefits include (FHWA 2013e):

- Reducing crashes of motorized vehicles by 15 percent;
- Decreasing delays (> 30 percent) for motorists;

- Increasing capacity (>30 percent) of roadways;
- Reducing vehicle speeds on the roadway;
- Providing space for landscaping within the right-of-way;
- Providing space to install additional roadway lighting, further improving the safety of the roadway;
- Providing space to provide supplemental signage on multilane roadways; and
- Potentially reducing cost, as raised medians can be less expensive to build and maintain than pavement.

FHWA also encourages the addition of medians and refuge islands because they can increase pedestrian, bicycle and motorized vehicle safety, helping to solve multiple challenges faced by transportation agencies. Medians allow pedestrians and bicyclists to cross one direction of traffic at a time, often allowing them to focus on just two to three lanes rather than having to anticipate traffic for the entire width of the road. Medians also provide a space to install improved lighting at pedestrian and bicycle crossing locations. Improved lighting has been shown to reduce nighttime pedestrian fatalities at crossings by 78 percent (FHWA 2013e).

Sufficiently wide raised medians and refuge islands can reduce the delay incurred by pedestrians waiting for a gap in traffic to cross. Shorter delays translate into fewer pedestrians taking risks by crossing through perceived openings in the traffic stream. On a four-lane roadway with average daily traffic (ADT) of 5,000 vehicles, medians can reduce pedestrians' delay waiting for a gap from 41 seconds to 9 seconds, or 79 percent (Dowling et al. 2008).

Crossing the street can be a complex task for pedestrians, especially under nighttime conditions. Pedestrians must estimate vehicle speeds, adjust their walking speeds, determine the adequacy of gaps, predict vehicle paths, and time their crossings appropriately. Drivers also face challenges: they must see pedestrians, estimate vehicle and pedestrian speeds, determine the need for action, and react in a timely fashion. Providing raised medians or pedestrian refuge areas at pedestrian crossings at marked crosswalks has demonstrated a 46 percent reduction in pedestrian crashes. At unmarked crosswalk locations, pedestrian crashes have been reduced by 39 percent (FHWA 2008). Installing raised pedestrian refuge islands on the approaches to unsignalized intersections has had the most impact reducing pedestrian crashes.

Medians can be especially beneficial in relation to transit stops, as many transit stops are located along higher-volume arterials at uncontrolled crossing locations. Providing medians can make these crossings safer and more appealing to existing and potential transit users.

4.2.7.2 *Getting Pedestrians Safely Across the Street*

FHWA strongly encourages the use of raised medians or refuge areas in curbed sections of multilane roadways in urban and suburban areas, particularly in areas that mix a significant number of pedestrians with high volumes of traffic (more than 12,000 vehicles per day) and intermediate or high travel speeds (FHWA 2008).

FHWA guidance further states that medians or refuge islands should be at least 4-ft. wide (preferably 8-ft. wide for accommodation of pedestrian comfort and safety) and of adequate length to allow the anticipated number of pedestrians to stand and wait for gaps in traffic before crossing the second half of the street (FHWA 2008). On refuges 6-ft. wide or wider that serve designated pedestrian crossings, detectable warning strips complying with the requirements of the ADA must be installed (U.S. Access Board 2011).

4.2.7.3 *Current AASHTO Policy and Guidance*

Chapter 4 of the Green Book addresses the motorized vehicle safety and operational aspects of providing medians and their design considerations. The Green Book's chapter on local roads

and streets notes that local urban streets often do not have medians, but where provided they are primarily used to enhance the environment and to act as buffer strips. The chapter on collector roads and streets notes that medians generally are not provided on rural collector roadways, but offers significant discussion of median use for vehicle traffic operations and safety purposes on urban collectors. The chapter on rural and urban arterials discusses the use and design of medians on rural arterials, but not in the context of their relationship to multimodal accommodation (AASHTO 2011a).

The discussion of urban arterials in Chapter 7 of the Green Book provides considerable information on the use and design of medians and their vehicle traffic operations and safety considerations. The discussion notes that medians are a desirable feature of arterial streets and should be provided where space permits. Relevant guidance regarding median relationship to all right-of-way users includes the following (AASHTO 2011a):

- Like refuge islands, medians can benefit pedestrians and bicyclists by allowing them to cross one direction of traffic at a time, provided they are at least “1.8 m [6 ft.] wide when they will be used by bicyclists”;
- “Where intersections are relatively infrequent (e.g., 1.0 km [0.6 mi] or more apart) and there is no developed frontage to generate pedestrian crossing needs, the median width may be varied by using a narrow width between intersections for economy and then gradually widening the median on the intersection approaches to accommodate left-turn lanes”; and
- “A raised curbed median may be used on low-speed urban arterial streets. This median type is used where it is desirable to manage access along an arterial street by preventing mid-block left turns. Raised curbed medians provide a refuge for pedestrians and a good location for signs and other appurtenances.”

4.2.7.4 General Principles and Considerations for Medians

General principles and design considerations for medians include the following:

- Landscaping on medians should be designed in a manner that does not obstruct sight distance triangles for any user mode;
- If medians are provided at intersections as refuge, they should be wide enough to accommodate groups of pedestrians, wheelchair users, bicyclists and people pushing strollers;
- On roadways where median dimensions need to remain continuous and left-turn lanes are provided, medians should be 16–18 ft. wide to allow for a turn lane plus pedestrian refuge;
- When designing median width, use an appropriate design vehicle for left turns and U-turns;
- At intersections in urban areas, set the width of medians only as wide as necessary to provide the desired function (accommodation of longitudinal left turns, pedestrian refuge and so forth) so that the intersection does not lose operational efficiency and to prevent vehicles crossing the median from using the width inappropriately (e.g., side-by-side queuing, angled stopping and so forth);
- On multilane roadways, a median of 6 ft. to 8 ft. in width can be helpful to a crossing pedestrian and more desirable than the same width added to another element of the roadway;
- In low-speed urban contexts, raised medians should be constructed with vertical curbs to provide refuge for pedestrians, access management, and a place to install signs, utilities and landscaping;
- In snow conditions, raised medians can improve delineation of the median, and if emergency access is a concern, mountable curbs should be considered in special locations;
- Narrow medians (4-ft.-wide or less) should only be used to restrict turning movements, to separate opposing directions of traffic and to provide space for traffic control devices;
- Where flush medians are desirable to maintain access to fronting property (e.g., suburban commercial corridors), consider using textured or colored paving or stamped concrete for

- the median lane, interspersed with raised landscaped islands to channelize turning traffic, divide opposing lanes of traffic and provide pedestrian refuge where appropriate (such as at mid-block and intersection crossings);
- At lower urban operating speeds (25 mph to 30 mph), generally no need exists to provide an offset between the median curb face and the travel lane;
- Unless a gutter pan is required for drainage, pave the inside travel lane up to the face of the median curb;
- If gutter pans are needed, use 6-in. to 1-ft. gutter pans unless typical flow requires more and avoid placing catch basins in median gutters;
- Design the median “nose” using state, local or AASHTO guidelines, ensuring proper end treatments to guide vehicles away from the median and pedestrian refuges;
- Design median turn lanes, tapers and transitions using state, local or AASHTO guidelines for intersection design; and
- At intersections with significant pedestrian crossings, and where the median is wide enough, extend the median nose beyond the crosswalk to provide an enclosed pedestrian refuge.

4.2.7.5 Trees and Landscaping in Medians

An important aspect of roadway landscape design is the treatment of trees and other fixed objects in roadsides and medians. Integrating trees into the design of a facility has many advantages. Trees provide a visual edge to the roadway that helps guide motorists. Trees also add to the aesthetic quality of a highway. In urban and suburban areas, trees soften the edges of arterial and collector streets, and they can be an important aspect of community identity. In general, roadway designers must balance safety with other community values when considering facility design and tree preservation. If sight distance is a concern, taller trees with lower branches that are trimmed or low-growing plants can offer landscaping options along both the roadway edge and in medians.

Generally, a tree with a trunk diameter greater than 4 in. (measured 4 in. above the ground line) is considered a *fixed object* along the roadway. Because most trees grow larger than this, their placement along the roadway and in medians needs to be carefully considered. Factors that affect tree placement include the roadway context, design and anticipated vehicle operating speeds, volumes of all users, roadway cross section, and placement of barriers. Chapter 10 in the AASHTO *Roadside Design Guide* (AASHTO 2011b) provides considerable discussion of roadside safety in urban and restricted areas and specifically addresses minimum offsets to both frangible and rigid objects beside the traveled way. Balancing the safety needs of all users can be challenging in designing urban and suburban roadsides and medians, but solutions can be found using the guidance in this document.

Additional information and mitigative strategies for trees in the public right-of-way can be found in:

- *NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan, Volume 3: A Guide for Addressing Collisions with Trees in Hazardous Locations* (Neuman et al. 2004), and
- *Landscaping of Highway Medians at Intersections* (CUTR 2013).

4.2.8 Mid-block Pedestrian and Bicycle Crossings

When a pedestrian or bicyclist crosses the roadway, this is considered a “crossing.” Most crossings occur at intersections, but pedestrians and cyclists sometimes find it more convenient to cross at a mid-block crossing location, particularly on roadways where adjacent signalized

intersections are widely spaced or where the nearest intersection crossing location creates substantial out-of-direction travel. Mid-block crossing opportunities also may be preferred because these locations involve no turning vehicles; pedestrians and bicyclists can focus their attention on through-moving vehicles while attempting to cross.

It is important for designers to consider the existing, anticipated and desired use of potential crossing locations both at mid-block and at intersections. Major considerations include the land uses on either side of the street and walking distances with and without a crosswalk. The AASHTO Pedestrian Facilities Guide emphasizes the importance of mid-block crossings in areas where intersections are spaced relatively far apart and pedestrian generators exist on both sides of the street: “Mid-block crossings are preferred because pedestrians should not be expected to make excessive or inconvenient diversions in their travel path to cross at an intersection” (AASHTO 2004a). In all locations, enhanced pedestrian crossing treatments should be considered based on the number of vehicle travel lanes and the speed and volume of vehicular traffic.

Where a pattern of mid-block crossings is present or anticipated, consideration should be given to providing a marked crosswalk. Properly designed and visible mid-block crosswalks encourage mid-block crossings to occur at the same locations (rather than being scattered along the block) and provide better visibility of pedestrians and bicyclists to drivers. According to the AASHTO Pedestrian Facilities Guide, some of the situations where marked mid-block crossings are most appropriate include:

- “Superblocks” where spacing between adjacent signalized intersections exceeds 600 ft.;
- Traffic generators located across the street from each other at a mid-block location;
- Schools with entrances near a mid-block location; and
- Mid-block transit stops (AASHTO 2004b).

Designers may use a variety of treatments to create convenient and comfortable crossings for pedestrians. These treatments include median crossing islands, crossing signs and markings, advance yield/stop lines, rectangular rapid flash beacons (RRFBs), pedestrian hybrid beacons and traffic signals. Existing guidance encourages the use of engineering judgment to develop a justification for the installation of a marked crosswalk, pedestrian hybrid beacon, traffic signal or other crossing treatment. The MUTCD includes flexibility for the designer to consider factors besides traffic volume during an engineering study to justify the installation of a beacon or traffic signal. The MUTCD also suggests that even if a traffic signal warrant is met, other treatments (at the designer’s discretion) may be more appropriate to create a safe crossing (FHWA 2009b).

4.2.8.1 Current AASHTO Policy and Guidance

The Green Book provides little guidance on the provision and design of mid-block pedestrian/bicycle crossings, and generally refers the reader to the AASHTO Pedestrian Facilities Guide (AASHTO 2004b) and the AASHTO Bicycle Guide (AASHTO 2014b) for guidance on pedestrian and bicycle facilities, respectively.

The Pedestrian Facilities Guide states that pedestrians should be encouraged to cross roadways at intersections because drivers have a greater expectation of encountering pedestrians at intersections than at mid-block crossings. This guide also recognizes that mid-block crossings have fewer conflict points between vehicles and pedestrians, which is a safety advantage over crossings at intersections. The Pedestrian Facilities Guide encourages that mid-block crossing locations be designed to increase drivers’ awareness of the location, increase drivers’ expectation of encountering pedestrians and encourage pedestrians to cross at the designated location (AASHTO 2004b).

The Pedestrian Facilities Guide also identifies three important distinctions between mid-block crossings and intersection crossings:

- Many more potential crossing locations occur mid-block than at intersections;
- Motorists are less likely to expect pedestrians crossing at mid-block; and
- Pedestrians with visual impairments have fewer audible clues for determining the best time to cross mid-block (AASHTO 2004b).

Based on these three distinctions, the AASHTO guide provides the following design considerations for designated mid-block crossing locations (AASHTO 2004b):

- Make the crossing location convenient for pedestrians. Mid-block crossing opportunities should be provided at locations where intersection crossing locations are not available or are inconvenient for pedestrians to use. Mid-block crossing locations should be conveniently placed to encourage pedestrians to use them rather than other unmarked mid-block locations that may seem more convenient.
- Alert drivers to potential crossings as they approach the crossing location. Drivers should be warned of pedestrian crossing locations in advance, and the mid-block crossing locations should be highly visible to approaching drivers. Mid-block crossing locations should be lit at night to improve driver awareness and pedestrian visibility. Drivers should have clear lines of sight to the crossing location so pedestrians who are crossing or waiting to cross are visible. The approach to the crossing location should encourage drivers to reduce their speed prior to the crosswalk. Drivers should be given plenty of time to recognize the presence of a pedestrian and stop in advance of the crosswalk.
- Make pedestrians aware of the opportunity to cross. Provide aids for pedestrians with visual impairments to recognize the presence of a mid-block crossing location and the best opportunities for crossing. Auditory and tactile information should be provided for pedestrians with visual impairments since cues at an intersection crossing location (such as the sound of traffic stopping and starting) are not always available mid-block.
- Alert drivers and pedestrians to their responsibilities and obligations at a crossing location and provide opportunities to meet these responsibilities/obligations. Use MUTCD guidance to establish a legal crossing location. Vehicle approach, pedestrian approach, and traffic control design should provide pedestrians with clear messages about when to cross and drivers about where to yield. Where necessary, a refuge area should be provided for pedestrians to complete the crossing in stages. Traffic control devices can be used to create gaps in traffic for pedestrians to cross.

The AASHTO Bicycle Guide states that the task of designing a mid-block crossing location between a pathway and a roadway involves consideration of several variables, including:

- Anticipated mix and volume of path users;
- Speed and volume of motorized vehicle traffic on the roadway being crossed;
- Configuration of the road; and
- Amount of sight distance that can be achieved at the crossing location (AASHTO 2014b).

The Bicycle Guide also presents the following geometric design guidance related to mid-block bicycle crossing locations:

- The mid-block crossing should be conspicuous to both road users and path users;
- Sight lines should be maintained to meet the needs of the traffic control provided;
- All approaches to the mid-block crossing location should be on relatively flat grades;
- Mid-block crossing locations should intersect the roadway at an angle as close to perpendicular as practical to minimize the exposure of crossing path users and maximize sight lines;
- The least amount of traffic control that is effective should be selected; and
- Designated mid-block crossing locations should be located a sufficient distance outside the functional area of adjacent intersections (AASHTO 2014b).

4.2.8.2 Principles and Considerations of Mid-block Pedestrian/Bicycle Crossings

General principles and considerations regarding the provision and location of mid-block crosswalks discussed in ITE's *Designing Walkable Urban Thoroughfares* include the following (ITE 2010a):

- Consider providing a marked mid-block crossing location where protected intersection crossings are spaced greater than 400 ft., or so that crosswalks are located no greater than 200 to 300 ft. apart in high pedestrian volume locations;
- Consider mid-block crossing opportunities when significant pedestrian demand exists to cross a street between intersections (e.g., to connect to major generators or transit stops); and
- Locate mid-block crosswalks at least 100 ft. from the nearest side street or driveway so that drivers turning onto the major street have a chance to notice pedestrians and properly yield to pedestrians crossing the street.

A 2005 FHWA report titled *Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations: Final Report and Recommended Guidelines* evaluated the safety considerations of providing marked versus unmarked crosswalks at uncontrolled locations. This report provides the following guidance (FHWA 2005):

Marked pedestrian crosswalks may be used to delineate preferred pedestrian paths across roadways under the following conditions:

- At locations with stop signs or traffic signals to direct pedestrians to those crossing locations and to prevent vehicular traffic from blocking the pedestrian path when stopping for a stop sign or red light.
- At non-signalized street crossing locations in designated school zones. Use of adult crossing guards, school signs and markings, and/or traffic signals with pedestrian signals (when warranted) should be considered in conjunction with the marked crosswalk, as needed.
- At non-signalized locations where engineering judgment dictates that the number of motorized vehicle lanes, pedestrian exposure, average daily traffic (ADT), posted speed limit, and geometry of the location would make the use of specially designated crosswalks desirable for traffic/pedestrian safety and mobility.

Marked crosswalks alone (i.e., without traffic-calming treatments, traffic signals and pedestrian signals when warranted, or other substantial crossing improvement) are insufficient and should not be used under the following conditions:

- Where the speed limit exceeds 40 mph.
- On a roadway with four or more lanes without a raised median or crossing island that has (or will soon have) an ADT of 12,000 or greater.
- On a roadway with four or more lanes with a raised median or crossing island that has (or soon will have) an ADT of 15,000 or greater.

The FHWA report also provides a summary table (reproduced here as Exhibit 4-18) containing recommendations for installing marked crosswalks and other needed pedestrian improvements at uncontrolled crossing locations.

Pedestrians and bicyclists crossing at mid-block need to see and be seen. According to NACTO, the following principles should be considered to improve the visibility near mid-block crossing locations (NACTO 2013):

- Use vertical elements, such as trees, landscaping, and overhead signing to help identify crosswalks and islands to drivers;
- Restrict parking in advance of a crosswalk;
- Install a curb extension;
- Stop lines in advance of mid-block crosswalks should be set back so that a person crossing the street is visible to the second driver when the first driver is stopped at the stop line; and
- Medians or safety islands create a two-stage crossing for pedestrians.

Mid-block crossing locations should not be provided where the horizontal or vertical alignment of the roadway limits drivers' sight distance, the view of the pedestrian approach to the crossing or the view of the crossing location itself.

Exhibit 4-18. Recommendations for installing marked crosswalks and other needed pedestrian improvements at uncontrolled locations.*

Roadway Type (Number of Travel Lanes and Median Type)	Vehicle ADT <9,000			Vehicle ADT >9,000 to 12,000			Vehicle ADT >12,000–15,000			Vehicle ADT >15,000		
	Speed Limit **											
	<48.3 km/h	56.4 km/h	64.4 km/h	<48.3 km/h	56.4 km/h	64.4 km/h	<48.3 km/h	56.4 km/h	64.4 km/h	<48.3 km/h	56.4 km/h	64.4 km/h
	(30 mph)	(35 mph)	(40 mph)	(30 mph)	(35 mph)	(40 mph)	(30 mph)	(35 mph)	(40 mph)	(30 mph)	(35 mph)	(40 mph)
Two lanes	C	C	P	C	C	P	C	C	N	C	P	N
Three lanes	C	C	P	C	P	P	P	P	N	P	N	N
Multilane (four or more lanes) with raised median***	C	C	P	C	P	N	P	P	N	N	N	N
Multilane (four or more lanes) without raised median	C	P	N	P	P	N	N	N	N	N	N	N

* These guidelines include intersection and mid-block locations with no traffic signals or stop signs on the approach to the crossing. They do not apply to school crossings. A two-way center turn lane is not considered a median. Crosswalks should not be installed at locations that could present an increased safety risk to pedestrians, such as where there is poor sight distance, complex or confusing designs, a substantial volume of heavy trucks, or other dangers, without first providing adequate design features and/or traffic control devices. Adding crosswalks alone will not make crossings safer, nor will they necessarily result in more vehicles stopping for pedestrians. Whether or not marked crosswalks are installed, it is important to consider other pedestrian facility enhancements (e.g., raised median, traffic signal, roadway narrowing, enhanced overhead lighting, traffic-calming measures, curb extensions), as needed, to improve the safety of the crossing. These are general recommendations; good engineering judgment should be used in individual cases for deciding where to install crosswalks.

** Where the speed limit exceeds 64.4 km/h (40 mi/h), marked crosswalks alone should not be used at unsignalized locations.

*** The raised median or crossing island must be at least 1.2 m (4 ft.) wide and 1.8 m (6 ft.) long to serve adequately as a refuge area for pedestrians, in accordance with MUTCD and AASHTO guidelines.

C = Candidate sites for marked crosswalks. Marked crosswalks must be installed carefully and selectively. Before installing new marked crosswalks, an engineering study is needed to determine whether the location is suitable for a marked crosswalk. For an engineering study, a site review may be sufficient at some locations, while a more in-depth study of pedestrian volume, vehicle speed, sight distance, vehicle mix, and other factors may be needed at other sites. It is recommended that a minimum utilization of 20 pedestrian crossings per peak hour (or 15 or more elderly and/or child pedestrians) be confirmed at a location before placing a high priority on the installation of a marked crosswalk alone.

P = Possible increase in pedestrian crash risk may occur if crosswalks are added without other pedestrian facility enhancements. These locations should be closely monitored and enhanced with other pedestrian crossing improvements, if necessary, before adding a marked crosswalk.

N = Marked crosswalks alone are insufficient, since pedestrian crash risk may be increased by providing marked crosswalks alone. Consider using other treatments, such as traffic-calming treatments, traffic signals with pedestrian signals where warranted, or other substantial crossing improvement to improve crossing safety for pedestrians.

Source: FHWA (2005)

4.2.8.3 Recommended Practice

The design of a mid-block crossing location and its associated traffic control depends on numerous factors, including:

- The design of the roadway and roadside,
- Characteristics of the road users,
- Vehicle, pedestrian and bicycle volumes,
- Traffic speed, and
- Trip purposes and other factors.

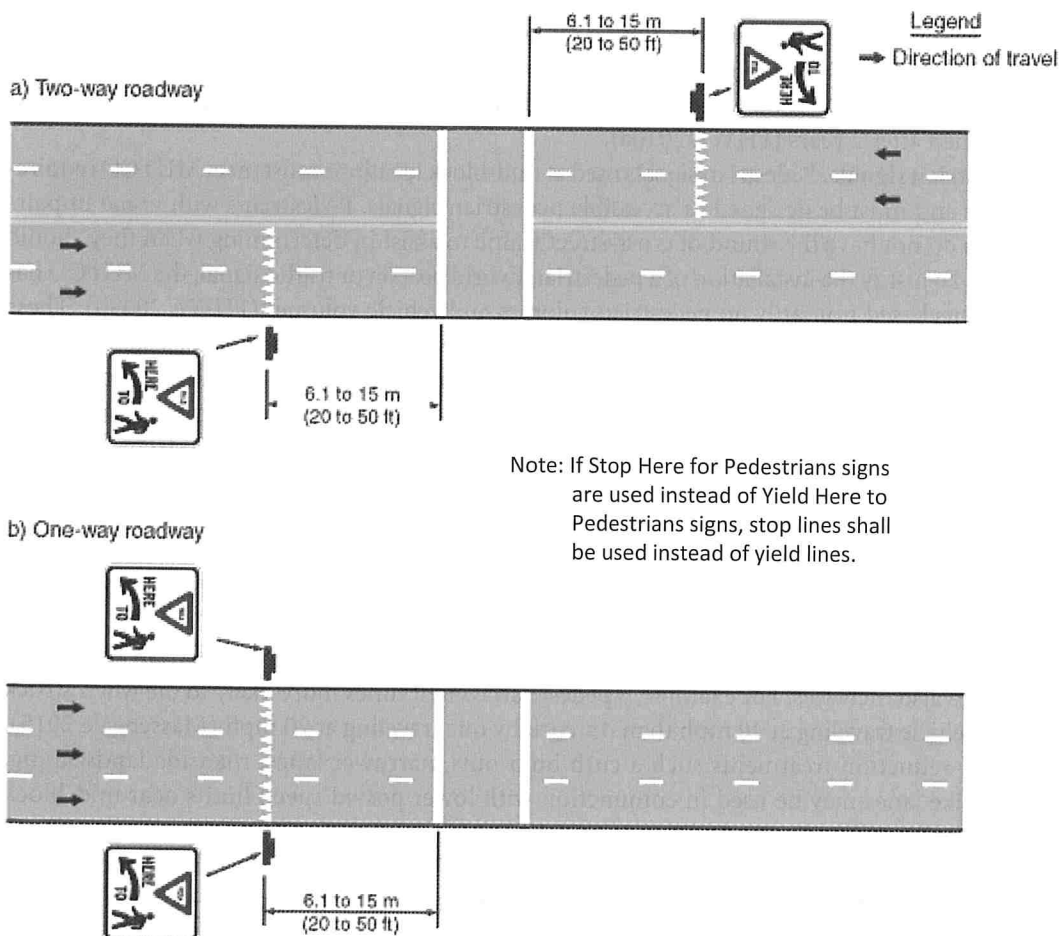
These factors will influence how the guiding principles are implemented; however, some guidance applies to all mid-block crossing locations. To establish a crosswalk at a non-intersection location, the law requires that white pavement markings consistent with MUTCD guidance must be used. In addition, curb ramps are required at mid-block crosswalks, unless the crosswalk is raised to the level of the sidewalk. The cross slope of a curb ramp should not exceed 2 percent, but can equal the grade of the street where this is not feasible. According to the U.S.

Access Board, the same 2 percent maximum for cross slope also applies to the crosswalk (U.S. Access Board 2011).

Specific traffic control and supplemental crosswalk features should be considered on higher-speed roadways where pedestrian or bicycle volumes are high, where sight distance is limited, or where there is a history of pedestrian or bicycle crashes. These features may include:

- **Yield lines or stop bars in advance of the crosswalk.** Using these pavement markings 30 ft. to 50 ft. in advance of the crosswalk can reduce the potential for “multiple threat” crashes, wherein one vehicle stops for a pedestrian or bicyclist but blocks the view of the pedestrian or bicyclist from the vehicle approaching in the adjacent lane (Van Houten 1988). As noted in the MUTCD, yield lines or stop bars indicate to drivers the appropriate location to yield or stop so that they do not “place pedestrians at risk by blocking other drivers’ views of pedestrians and by blocking pedestrians’ views of vehicles approaching in the other lanes” (FHWA 2009b). Normally, in order to increase visibility, parking should be prohibited in between the yield or stop line and the crosswalk. Exhibit 4-19 shows yield lines in advance of an unsignalized mid-block crosswalk.
- **“Yield to Pedestrians” or “Stop for Pedestrians” signs.** Tall, narrow signs can be installed at a lane line, the centerline, or in a median at an unsignalized crosswalk to call attention to the crossing location and remind drivers of their legal requirement to allow pedestrians to

Exhibit 4-19. Examples of yield lines at unsignalized mid-block crosswalks.



Source: Adapted from MUTCD (FHWA 2009b)

cross (FHWA 2005). Studies have shown that these signs increase driver yielding compliance (Byszeski 2003). The signs frequently are struck, however, requiring maintenance and replacement, and they also may need to be removed for snow removal activities. Similar overhead signs oriented horizontally can be used above the mid-block crossing location (FHWA 2009b).

- **Raised crosswalk.** Because raised crosswalks effectively serve as speed humps for vehicles, they should only be used on low-speed non-emergency routes. They should be clearly marked, and advanced warning should be used to alert drivers to their presence. Raised crosswalks eliminate the need for curb ramps, as they allow pedestrians and bicyclists to cross at the level of the sidewalk. Detectable warnings are needed at the transition from the sidewalk to the crosswalk to assist pedestrians with visual impairments who generally rely on curb ramps for guidance.
- **Lighting.** Lighting should be considered where nighttime pedestrian or bicycle crashes are a concern and where little or no roadway lighting exists in the area. According to the FHWA, either direct or back lighting is effective (FHWA 2006b).
- **Flashers and beacons (constant or actuated).** Mounted on the post of advance warning signs, on the post of warning signs at the crosswalk, or on an overhead structure above the crosswalk, beacons and flashers call drivers' attention to the crossing location. Some beacons flash continuously whereas others are actuated by pushbuttons or sensors. They may be circular or rectangular and have a steady or varying flash pattern. At uncontrolled crossings where a signal or pedestrian hybrid beacon is not warranted, cost prohibitive or deemed unnecessary, designers may consider supplementing pedestrian, bicycle/pedestrian or school-crossing warning signs with RRFBs. RRFBs have been shown to increase driver yielding rates at the crosswalk (Fitzpatrick 2001). Generally, this treatment should be used with caution at crossings with more than two lanes without a refuge. FHWA's *Effects of Yellow Rectangular Rapid-Flashing Beacons on Yielding at Multilane Uncontrolled Crosswalks* found an 88 percent average compliance rate for motorists yielding to pedestrians at crossings with RRFBs; this rate was sustained after 2 years (FHWA 2010a).
- **Pedestrian signals.** Pedestrian signals used at mid-block locations must meet MUTCD requirements and must be designed as accessible pedestrian signals. Pedestrians with visual impairments do not have the sound of cross-street traffic to assist in determining when they should cross. To justify the installation of a pedestrian hybrid beacon or traffic signal, the MUTCD has warrants based primarily on pedestrian volumes and vehicle volumes (FHWA 2009b). These warrants are used to help allocate limited financial resources. In some cases, pedestrians may not be crossing the street in sufficient numbers to satisfy the warrant because there are not adequate gaps in traffic or because the pedestrians do not feel comfortable doing so. Where medians are present, actuators should be located in the median to allow pedestrians to reactivate the signal if they were not able to complete the crossing. These median signals also should be designed for accessibility (U.S. Access Board 2011). Where mid-block pedestrian signals are closely spaced with traffic signals at intersections, they should be coordinated with nearby intersection signals to increase efficiency and reduce rear-end crashes (Zegeer 2002); otherwise, signal activation should immediately follow actuation.
- **Speed-reduction treatments.** As vehicle speeds increase, the severity of pedestrian and bicycle crashes also increases. For example, a pedestrian is eight times more likely to die when struck by a vehicle traveling at 40 mph than if struck by one traveling at 20 mph (Massengale 2015). Speed-reduction treatments such as a curb bulb-outs, narrower lanes, roadside landscaping, and bike lanes may be used in conjunction with lower posted speed limits near mid-block crossing locations.
- **Grade-separated crossing opportunity (pedestrian bridge or tunnel).** When pedestrian or bicycle volumes are very high and interfere with vehicular traffic flow, a grade-separated crossing location should be considered. This design solution also works well between two major mid-block traffic generators, across facilities where pedestrians or bicyclists are not permitted (such as

freeways) and at locations where an at-grade crosswalk is not ideal due to various site characteristics but where pedestrians or bicyclists tend to cross anyway. When used, grade-separated crossing locations must be accessible and must not substantially increase crossing time or pedestrians/bicyclists will choose to cross at grade rather than use the grade-separated crossing structure.

- **Medians or crossing islands.** The Pedestrian Facilities Guide **states** that a crossing island should be considered “where the crossing exceeds 60 ft.” (AASHTO 2004a). Raised medians or pedestrian crossing islands are a “proven safety countermeasure” and have demonstrated a 46 percent reduction in pedestrian crashes. Pedestrian refuge areas or islands allow crossings to be completed in two stages and significantly reduce the distance a pedestrian must cross at one time. These features also can provide traffic-calming benefits and prohibit turning movements at nearby driveways, even on two-lane roads. FHWA’s *Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations* found that providing raised medians on multi-lane roads “can significantly reduce the pedestrian crash rate and also facilitate street crossing” (FHWA 2005). On roadways with a raised median and volumes exceeding 15,000 ADT, however, a marked crosswalk is considered appropriate only with additional crossing treatments. Crossing islands should be a minimum of 6 ft. wide and situated at locations where bicycles may be crossing (e.g., where a shared-use path crosses a roadway), “10 ft. is preferred to accommodate a bicycle with a trailer” (AASHTO 2014b). Additional information on pedestrian and bicycle crossing refuge islands is provided in a separate section of this chapter.

Additional implementation guidance on many of these treatments can be found in the MUTCD (FHWA 2009b) and the *Traffic-Control Devices Handbook* (ITE 2009a). Where special traffic control is used, advanced warning signs should make drivers aware of its presence before they encounter the crossing. The AASHTO Bicycle Guide (AASHTO 2014b) provides additional examples of treatments specifically for locations where shared-use paths cross roadways at mid-block. Exhibit 4-20 shows an example of a shared-use path that is stop-controlled for bicyclists at a mid-block crosswalk.

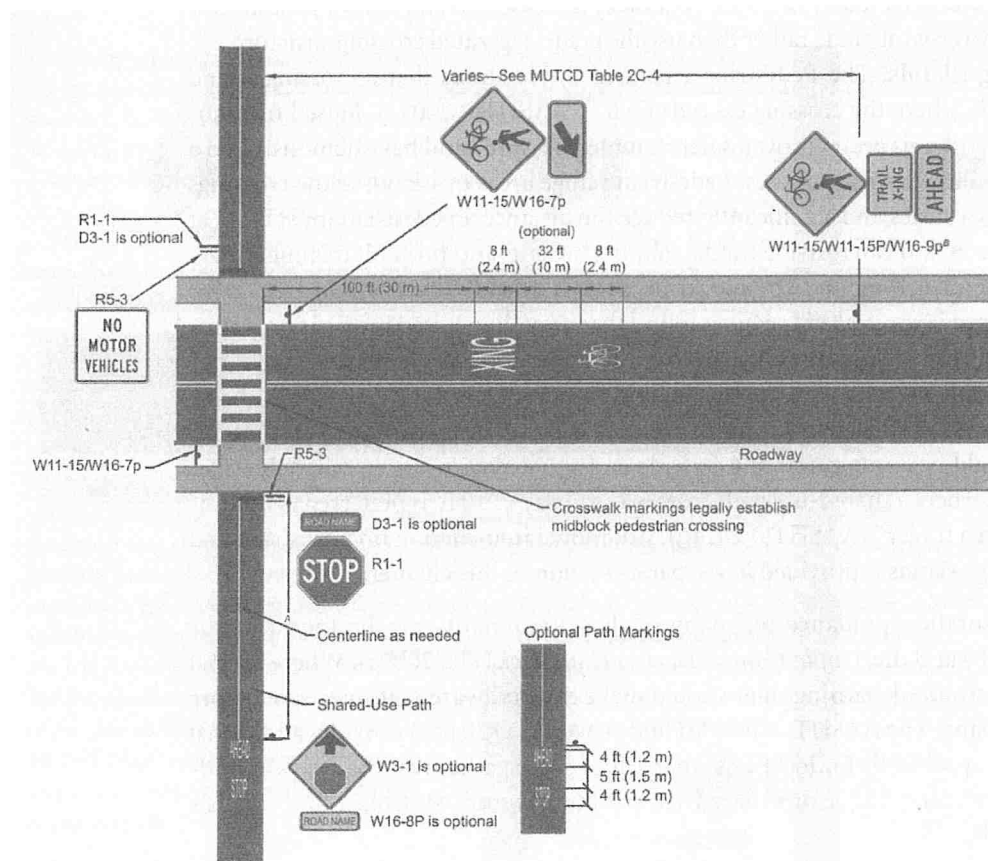
4.2.9 Pedestrian and Bicycle Crossing Refuge Islands

Refuge islands provide a protected area for pedestrians and bicyclists within intersection and mid-block crossings. Refuge islands can be either raised (as shown in Exhibit 4-21), or painted flush. In multimodal urban areas, it is desirable that roadways have shorter crossings, so on wide roadways or where less mobile pedestrians need to cross, refuge islands provide a location for pedestrians or bicyclists to wait partially through their crossing. Refuge islands also break up crosswalks at complex multilane and multileg intersections, making it possible for pedestrians to cross in shorter and easier portions.

Several types of medians and pedestrian crossing islands exist. Appropriately designed and applied medians and crossing islands improve safety, providing benefits to pedestrians and vehicles in the following ways:

- They may reduce pedestrian crashes by 46 percent and motorized vehicle crashes by up to 39 percent (FHWA 2008);
- They may decrease delays by greater than 30 percent for motorists (FHWA 2008);
- They allow pedestrians a safe place to stop at the midpoint of the roadway before crossing the remaining distance;
- They enhance the visibility of pedestrian crossings, particularly at unsignalized crossing points;
- They can reduce the speed of vehicles approaching pedestrian crossings;
- They can be used for access management for vehicles (allowing only right-in/right-out turning movements); and
- They provide space for supplemental signage on multilane roadways.

Exhibit 4-20. Example of mid-block crossing of shared-use path (path stop-controlled for bicyclists).



Notes:

- ^A Advance warning signs and solid centerline striping should be placed at the required stopping sight distance from the roadway edge, but not less than 50 ft (15 m).

Source: AASHTO (2014b)

Exhibit 4-21. Raised pedestrian and bicycle refuge island in Kansas City, KS.



Mid-block locations account for more than 70 percent of pedestrian fatalities (FHWA 2008). Vehicle travel speeds are higher at mid-block, which contributes to the larger injury and fatality rate seen at these locations. More than 80 percent of pedestrians die when hit by vehicles traveling at 40 mph or faster, whereas less than 10 percent die when hit at 20 mph or less (FHWA 2008). Installing such raised channelization on approaches to multilane intersections has been shown to be especially effective. Medians are a particularly important pedestrian safety countermeasure in areas where pedestrians access a transit stop or other clear origins/destinations across from each other. Providing raised medians or pedestrian refuge areas at marked crosswalks has demonstrated a 46 percent reduction in pedestrian crashes. At unmarked crosswalk locations, medians have demonstrated a 39 percent reduction in pedestrian crashes.

In summary, refuge islands provide the following benefits to pedestrians and bicyclists crossing a roadway:

- **Reduced exposure time.** Refuge islands reduce exposure time during the crossing by allowing the crossing to be completed in two stages. At multilane crossing locations, pedestrians and bicyclists need to determine a safe gap for several lanes of traffic at a time, which can be a daunting task. Refuge islands allow pedestrians and bicyclists to cross one direction of traffic at a time.
- **Refuge while waiting for acceptable gap.** At unsignalized intersections, refuge islands provide a storage area for pedestrians while they wait for acceptable gaps in traffic before completing the second half of the crossing maneuver.
- **Accommodation of shorter crossing phase.** At signalized intersections, refuge islands provide a storage area for pedestrians to wait for the next available cycle if they are unable to cross the street entirely during a provided crossing phase. This also helps with the efficiency of the intersection LOS by permitting split signal phasing for major turning movements.
- **Traffic calming.** Refuge islands may provide traffic-calming benefits by physically narrowing the roadway and potentially restricting motorized vehicle left-turn movements.

4.2.9.1 Current AASHTO Policy and Guidance

The Green Book provides the following limited guidance on the provision of refuge islands: “Where intersections are channelized or a median is provided, consideration should be given to the use of curbing for those areas likely to be used by pedestrians for refuge when crossing the roadway” (AASHTO 2011a). For more specific information on pedestrian and bicycle facilities, the Green Book generally refers the reader to the AASHTO Pedestrian Facilities Guide (AASHTO 2004b) and the AASHTO Bicycle Guide (AASHTO 2014b).

According to the Pedestrian Facilities Guide, some situations in which refuge islands are most appropriate include:

- Two-way arterial streets with high traffic volumes, high travel speeds, and large pedestrian volumes;
- Wide two-way intersections with high traffic volumes and significant numbers of crossing pedestrians;
- Two-way collector and local access streets where they function as traffic-calming devices and street crossing aids; and
- Complex or irregularly shaped intersections where islands could provide a pedestrian with the opportunity to rest and become oriented to the flow of oncoming traffic (AASHTO 2004b).

In addition, depending on the signal timing, refuge islands should be considered at signalized intersections where the crossing distance exceeds 60 ft., but can be used at intersections with shorter crossing distances where a need has been recognized. Median refuge islands should not be used to justify a signal timing that does not allow pedestrians to complete their crossing in one cycle (AASHTO 2004b).

The AASHTO Bicycle Guide refers to refuge islands as “crossing islands” and states that raised crossing islands are associated with significantly lower pedestrian crash rates at multilane crossings. Although crossing islands can be helpful on most road types, they are of particular benefit at path-roadway intersections in which one or more of the following apply:

- High volumes of roadway traffic and/or speeds create difficult crossing conditions for path users;
- Roadway width is excessive given the available crossing time; and
- The roadway cross section is three or more lanes in width (AASHTO 2014b).

4.2.9.2 Principles and Considerations of Pedestrian and Bicycle Refuge Islands

Refuge islands often are desirable in locations where providing the opportunity for a staged crossing (crossing one direction of traffic at a time) would be particularly beneficial to pedestrians. Such locations may include unsignalized mid-block crossing locations across a high-volume or high-speed facility with four or more lanes (or that exceed 60 ft.), signalized mid-block crossing locations where users may walk slower than 3.5 ft. per second (e.g., children, older adults, and persons with limited mobility), and in special circumstances, such as near a school (ITE 2010a). Providing raised medians or refuge islands at marked crosswalks has demonstrated a 46 percent reduction in pedestrian crashes (FHWA 2008).

The width of the median refuge island is determined by expected bicycle and pedestrian volumes, the constraints of the street to be crossed and the surrounding environment. At locations where pedestrian volumes are low, a relatively narrow median may be sufficient; where pedestrian volumes are higher or where crossing can be difficult due to high traffic volumes and speeds, a wider crossing island may be desired to provide space for larger groups of waiting pedestrians (AASHTO 2004b). In general, refuge islands should be large enough to accommodate as many potential users as possible, including groups of pedestrians or cyclists, tandem bicycles, pedestrians pushing strollers, wheelchairs and even equestrians if they are permitted to use the crossing path or roadway (AASHTO 2014b).

Access to the refuge island should be functional and safe for all users, and should be designed to meet the requirements of the proposed PROWAG (U.S. Access Board 2011). A cut-through design or a ramped design large enough to enable a wheelchair to wait on top of the island should be provided. The cut-through width should be the same as the complete width of the crosswalk, or it should at least maintain a minimum clear width. Cut-through ramps should be graded to drain quickly and should include detectable truncated dome warning surfaces so that pedestrians with vision impairments can identify the edge of the street (AASHTO 2004b). At signalized crossing locations, pedestrian actuators should be provided in the median to ensure that pedestrians who start the crossing late in the cycle or who travel slowly are not trapped in the median without being able to activate another crossing phase.

Lighting can be used to increase the visibility of the island to motorists and the crossing to pedestrians and cyclists. Landscaping in the median can be used as a traffic-calming strategy to reduce speeds, but care should be taken to ensure that landscaping features do not obscure the visibility of crossing users to motorists (AASHTO 2004b, NACTO 2014).

Motorists should be given substantial advanced notice of the median through an approach nose, offset from the edge of the traffic lane (AASHTO 2011a), and through marking, signing, reflectorization, or lighting (Florida DOT 1999). Proper visibility of the median also is critical for snowplow crews. Crossing islands should be well maintained; snow should be cleared in a way that does not block pedestrian or bicycle access, and any debris that accumulates in the median should be cleared frequently (NACTO 2014).

4.2.9.3 Recommended Practice

Where used on two-way streets, median refuge islands should be placed along the centerline of the roadway between the opposing travel lanes (NACTO 2014). Medians expected to be used as pedestrian refuges should have vertical curbs to delineate the pedestrian refuge from the surrounding roadway (ITE 2010a).

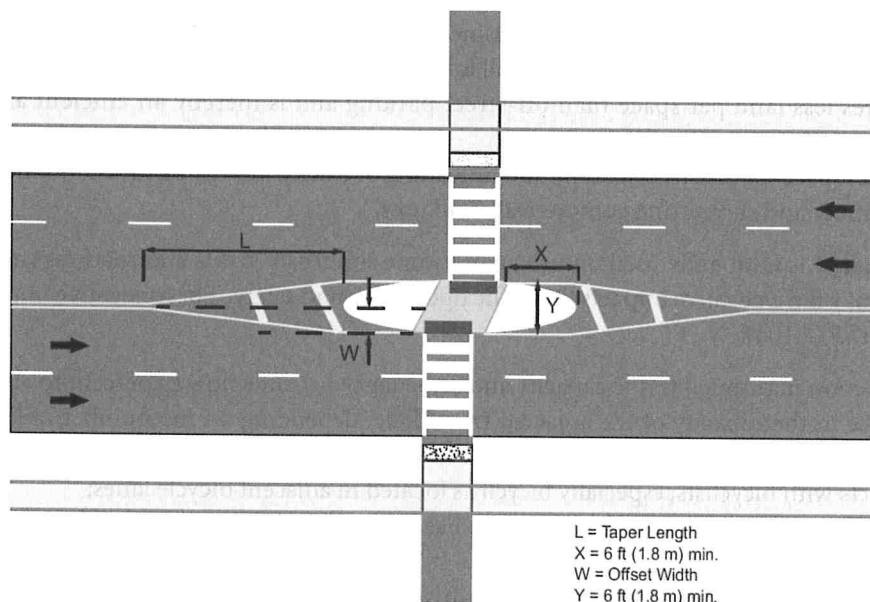
In areas where snow accumulation can occur, retroreflective white or yellow material should be supplemented with reflective delineators visible above the surface of the snow to snow plow crews (AASHTO 2014b). The MUTCD provides guidance for the pavement markings that should be used on the approach to the refuge island. For all medians at intersections, the nose should extend past the crosswalk. The nose protects people waiting on the median and slows turning drivers (NACTO 2013).

The refuge area also may be designed with a storage area aligned perpendicularly across the island or via a diagonal or offset storage bay, as shown in Exhibit 4-22. A diagonal storage area has the added benefit of helping to position pedestrians and bicyclists to face oncoming traffic; therefore, it should be angled toward the direction from which traffic is approaching. It should be recognized however, that a refuge island with diagonal or offset storage might complicate the crossing for pedestrians who have visual impairments. If pedestrians will use the storage area (or cut-through), the 45-degree angle of the curb should transition back to being perpendicular to the street to provide proper directional cues for the blind (NACTO 2014).

The cut-through or ramp width should equal the width of the crosswalk. Where this cannot be achieved, the crosswalk should not be striped narrower than the cut-through area just to match the width of the median cut-through or ramp (NACTO 2013). Crossing through pedestrian refuges must be accessible with channels at street grade, detectable warnings, and audio and visual output at signalized crossings (ITE 2010a).

The minimum dimensions for a refuge island serving typical crossings is 6 ft. wide and 20 ft. long, equivalent to at least 120 square ft. A width of 8 ft. or 10 ft. is preferred, as it provides additional separation distance from traffic and additional storage space, and the preferred length of

Exhibit 4-22. Crossing island.



Source: AASHTO (2014b), Figure 5-22

such a median is 40 ft. (NACTO 2013, NACTO 2014). Refuge islands used for a multi-use trail are recommended to be 10 ft. wide, with a minimum of 8 ft. wide (ITE 2010a).

4.2.10 Parking Configuration and Width

On-street parking serves several needs in urban and suburban environments. It supports economic activity by providing easy access to local merchants in commercial and mixed-use areas and to residents and visitors in residential areas. On-street parking also serves as an indication to motorists that they are entering a low- to intermediate-speed area where increased pedestrian activity should be expected, and it increases pedestrian comfort by separating pedestrians from moving traffic.

Usually, on-street parking alone is insufficient to meet all of the parking demand created by adjacent land uses; typically, on-street parking will be used to supplement the off-street parking supply.

On-street parking may provide the following benefits when properly designed and located along streets and roadways (ITE 2010a):

- Supports local economic activity of merchants by providing proximate access to local uses, as well as visitor needs in residential areas;
- Increases pedestrian comfort by providing a buffer between pedestrians and moving traffic helping reduce vehicle splash, noise and fumes;
- Slows traffic, making pedestrian crossing safer;
- Enables drivers and their passengers to become pedestrians conveniently and safely;
- Provides an indication to the motorist that desired operating speeds are reduced and that they are entering a low or moderate travel speed area;
- Provides the shortest accessible route to a street-fronting building entrance for pedestrians who have disabilities;
- Increases pedestrian activity on the street since people will walk between their parking space and destination, providing more exposure to ground-floor retail and increasing opportunities for social interactions;
- Supports local economic activity by increasing the visibility of storefronts and signs to motorists parking on the street;
- Reduces development costs for small business by decreasing on-site parking needs, particularly in urban infill development on small lots;
- Requires less land per space than off-street parking and is thereby an efficient and cost-effective way to provide parking; and
- Provides space for on-street loading and unloading of trucks, increasing the economic activity of the street and supporting commercial retail uses.

Although it is frequently used on urban and some suburban streets and roadways, on-street parking may have negative impacts on traffic operations and safety. These negative impacts can include (ITE 2010a):

- A reduction in through traffic capacity and impedance to traffic flow (3 percent to 30 percent decrease in the capacity of the adjacent travel lane, depending on the number of lanes and frequency of parking maneuvers);
- Conflicts with bicyclists, especially bicyclists located in adjacent bicycle lanes;
- Occupation of street width that could be used for other functions (e.g., bike lanes, wider roadsides);
- Visual obstructions near intersections and driveways; and
- An increase in crashes.

Designers should carefully consider the site-specific conditions to determine whether on-street parking is appropriate for a given block or roadway segment. The designer needs to balance traffic capacity and local access needs when deciding where and when to permit on-street parking. Methods are available for minimizing the impact of parking maneuvers on traffic flow. For an example, see the MUTCD (Section 3B.19, Figure 3B-21) for a parallel parking configuration that allows vehicles to drive forward into the parking space (FHWA 2009b).

4.2.10.1 *Current AASHTO Policy and Guidance*

The Green Book notes that within urban areas and rural communities, on-street parallel parking should be considered to accommodate existing and developing land uses. The Green Book states that the “designer should consider on-street parking so that the proposed street or highway improvement will be compatible with the land use . . . the type of on-street parking should depend on the specific function and width of the street, the adjacent land use, traffic volume, as well as existing and anticipated traffic operations” (AASHTO 2011a)

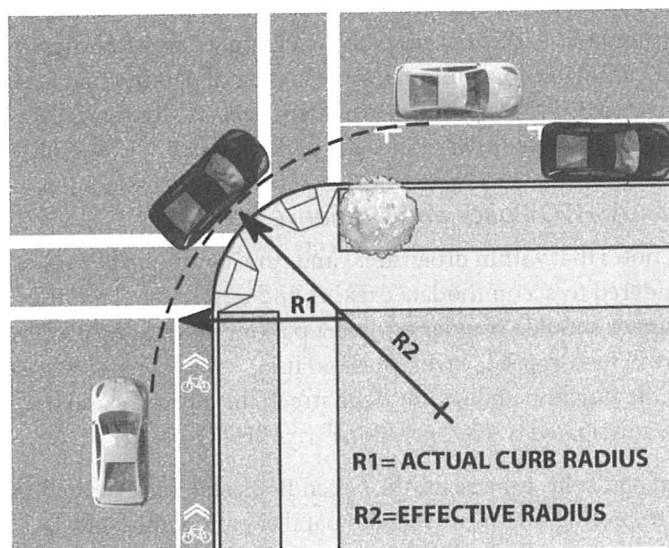
On urban arterial and collector streets, the Green Book states the desired minimum width of a parking lane is 8 ft., noting that most vehicles parallel park within 6 to 12 in. of the curb face and, on average, occupy 7 ft. of actual street space. It also notes that 10- to 12-ft. parking lanes may be desirable to provide better clearance from the traveled way, accommodate use of the parking lane during peak periods as a through travel lane, and/or accommodate transit operations. Parking lanes that are 7 ft. wide have been successfully used on urban collector streets within residential neighborhoods that strictly accommodate passenger vehicles. On local streets, on-street parking is generally permitted, but specific parking lanes are not usually designated (AASHTO 2011a).

Angle parking is acceptable under certain circumstances, but the Green Book notes that angle parking presents special problems because longer vehicles may interfere with the traveled way and introduce sight distance issues associated with certain types of vehicles (AASHTO 2011a). The type of on-street parking for a street or corridor should be selected based on the function and width of the street, the adjacent land use, traffic volume, and existing and anticipated traffic operations.

The Pedestrian Facilities Guide primarily addresses issues associated with pedestrians and parking lanes near intersections. Parked vehicles in a parking lane may cause sight obstructions and result in pedestrians stepping into the parking lane to see around parked vehicles before crossing an intersection. Curb extensions can improve sight lines at intersections so that pedestrians can see and be seen. However, curb extensions may not be practical at all locations where parking is permitted. The Pedestrian Facilities Guide provides guidance on the design of street corners to allow turning vehicles to clear adjacent parking lanes and align with the departing travel lane, as shown in Exhibit 4-23 (AASHTO 2004b).

Guidance in the AASHTO Bicycle Guide is consistent with that of the Green Book, indicating that 8 ft. is the desired width of a parking lane adjacent to a bicycle lane, and 7 ft. is the minimum width. The Bicycle Guide provides additional guidance related to the design of parallel and diagonal parking adjacent to bicycle lanes. Where parallel parking is permitted but the parking lane or stalls are not specifically designated, the recommended width of the shared bicycle and parking lane is 13 ft., whereas a minimum width of 12 ft. may be satisfactory where parking usage is low and turnover is infrequent (AASHTO 2014b).

In areas with high parking demand and sufficient street width, diagonal parking is sometimes used to increase parking capacity and reduce travel speeds, but bicycles lanes should not be placed adjacent to conventional front-in diagonal parking because drivers in the parking spaces have poor visibility of bicyclists in the bike lane. Where diagonal parking is preferred, back-in

Exhibit 4-23. Effective turning radius.

Source: AASHTO (2004b)

diagonal parking is recommended to mitigate conflicts associated with bike lanes adjacent to angle parking. Additional benefits of back-in diagonal parking for all roadway users include:

- Sight distance is improved between exiting motorists and other traffic;
- Passengers, including children, are channeled toward the curb when alighting; and
- Vehicles' trunks can be more easily loaded and unloaded because they are located at the curb and not in the street.

4.2.10.2 On-Street Parking Principles and Considerations

Designing Walkable Urban Thoroughfares (ITE 2010a) provides the following general principles and considerations regarding on-street parking:

- The characteristics and functionality of the street, needs of adjacent landowners, applicable local policies, and plans for parking management should determine the need for on-street parking;
- Where street parking is needed on higher volume urban streets, parallel parking should be used;
- Angle parking may be used on low-speed and low-volume collector streets with ground-floor commercial uses, primarily those serving as main streets;
- On-street parking should generally be prohibited on streets with speeds greater than 35 mph; and
- Widths of parking lanes are dependent on the context of the area, the functionality of the street, the expected vehicle use, and the anticipated frequency of parking turnover.

The ITE design guide also reaffirms the necessity of conforming to accessibility requirements. Where vehicle capacity (i.e., mobility) needs to be balanced with on-street parking (i.e., accessibility), consider using the curb lane for parking during off-peak periods and for traffic during peak periods. This strategy requires daily enforcement and immediate towing of violators, but it will have an impact on the walkability of the roadside during peak hours. This strategy should be considered where traffic congestion causes significant delays to adjacent residential neighborhoods or in areas with poorly connected networks and limited alternative routes (ITE 2010a).

4.2.10.3 Recommended Practice for On-Street Parking Lanes

Consistent with current AASHTO policy, the desirable width of a parallel on-street parking lane is 8 ft. in most locations. Within residential areas and/or constrained rights-of-way, 7-ft. parking lanes can be used. When it is desirable to narrow the parking lane to allocate additional space for bicyclists within a bicycle lane, the bicycle lane and/or buffer should be widened consistent with the change in parking lane width. Otherwise, if the parking lane is narrowed and the bicycle lane width is left unchanged, the bicycle lane shifts toward the curb, and no additional operating space is afforded to bicyclists (Furth et al. 2010).

4.2.10.4 Additional Guidance

A summary of additional guidance for on-street parking lanes includes:

- By narrowing the parking lanes (e.g., to 8 ft. or 7 ft. wide), the proportion of vehicles parked closer to the curb is expected to increase (Furth et al. 2010);
- For parking lanes 7 ft. to 9 ft. wide, the dooring zone for parked vehicles extends approximately 11 ft. from the curb (see Section 4.2.D on the design of bicycle lanes) (Torbic et al. 2014);
- Angle parking is permissible where operating speeds are 25 mph or lower and the delay produced by parking maneuvers is acceptable;
- Where practical or on bicycle routes, back-in angle parking is preferable to front-in angle parking;
- Trade-offs associated with different angles of parking include that lower angle parking results in fewer parking spaces, higher angle parking requires a wider adjacent travel lane to keep parked vehicles from backing into the opposing travel lane when exiting the parking space, and back-in angle parking requires a wider edge zone in the roadside due to the longer overhang at the rear of most vehicles, a narrower travel lane adjacent to parking for maneuvering, and less depth for the parking stall due to the longer overhang of the curb (ITE 2010a);
- Reverse (back-in) angled parking requires a wider edge zone in the roadside due to the longer overhang at the rear of most vehicles, but this extra width can be compensated for by the narrower travel lane that is needed adjacent to parking for maneuvering and by less depth needed for the parking stall, as the longer overhang is over the curb;
- For parallel parking, provide a minimum 1.5-ft. wide offset between the face of the curb and edge of potential obstructions such as trees and poles to allow for the opening of car doors (ITE 2010a);
- Unless curb extensions are provided, prohibit parking within at least 20 ft. from the nearside of mid-block crosswalks and the curb return of stop-controlled intersections and within at least 30 ft. from approaches to signalized intersections (ITE 2010a); and
- At bus stops, intersections, and mid-block crossings, extend curbs by 6 ft. into the parking lane to improve pedestrian visibility (ITE 2010a).

4.2.11 Traveled Way Transition Design

Transitions may refer to a change in the width, cross section, or speed of a roadway, or to the need to laterally shift vehicles in travel lanes.

In terms of geometric design, transitions refer to the provision of an adequate taper where lanes shift or narrow, shoulders widen, or lanes diverge or merge, and where deceleration lanes are provided. Geometric transitions usually are required when a change occurs in the roadway type with an associated change in width, particularly where functional classification and speed changes occur and where a narrowing or widening of lanes or a decrease or increase in the number of lanes is introduced.

In terms of vehicle operating speeds, where high-speed facilities (50 mph and higher) meet low- or intermediate-speed (45 mph and lower) facilities, there is a transition zone where drivers are expected to slow to a speed suitable for the environment and context zone they are entering. The speed transition zone is not a specific point along the roadway where an abrupt speed change occurs, but rather an extended length of roadway over which travel speed transitions from higher to lower to recognize changes in context, community goals and increased levels of multimodal activity and access points.

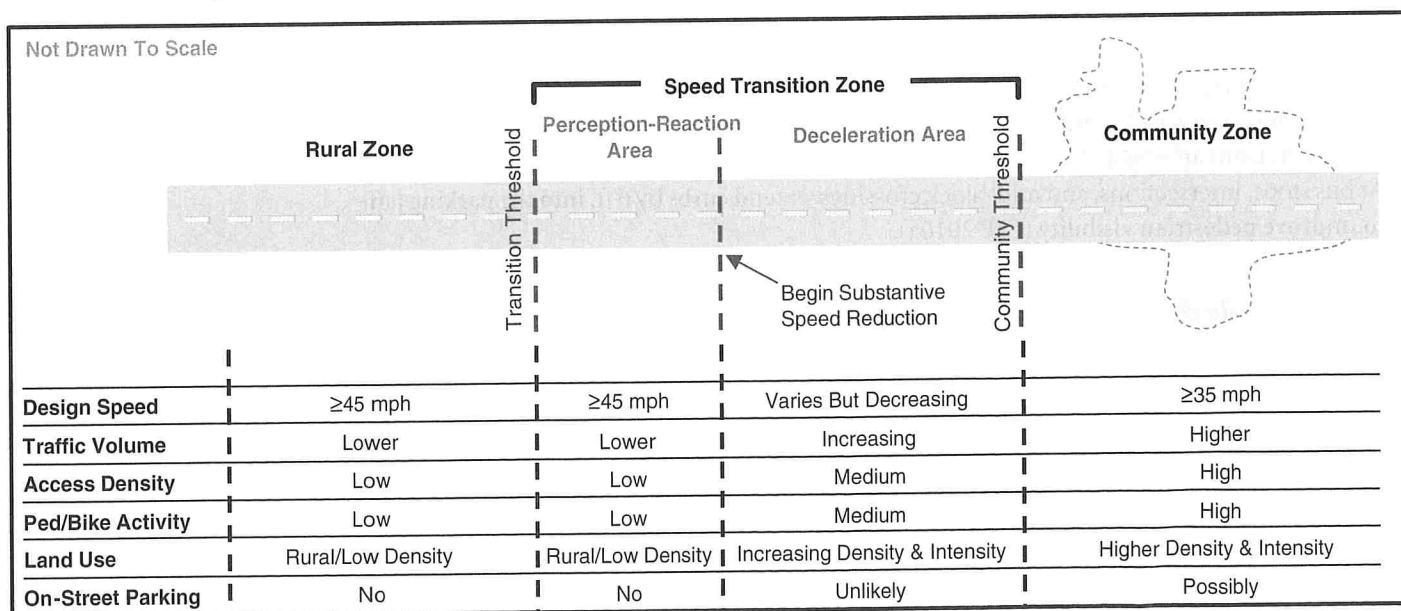
Designs that encourage gradual speed reductions over the length of the speed transition zone are preferred to designs that result in sudden reductions in speed at the end of the speed transition zone. Well-designed speed transition zones incorporate traffic control devices along with roadway and roadside design features that convey the need to reduce speed and encourage gradual reductions in speed (Torbic et al. 2012).

Physical changes in roadway alignment or width are the treatments most likely to affect driver behavior and reduce speeds. According to Forbes (2011), driver speeds will decrease as roadway deflection increases, so designers should consider changes in the roadway alignment to physically slow motorists. Gateway treatments, such as roundabouts (a FHWA-proven safety countermeasure), chicanes, raised medians, reduced lane widths, shoulder removal, providing a curb-line and/or including tall vegetation (e.g., hedges, trees) have been shown to be effective at reducing travel speeds approaching a main street (Forbes 2011). Where present, bicycle facilities should be carried through gateway treatments.

Exhibit 4-24 illustrates a typical speed transition zone for a high-speed rural highway entering a land use context that is suburban, urban or a small community or town. As discussed by Torbic et al. (2012), the characteristics of the speed transition zone and adjacent segments can be described as follows:

- **The rural zone.** The rural zone consists of a high-speed (i.e., posted speed limit ≥ 45 mph) rural road with little roadside development, few access points and relatively few features or potential conflicts that require driver attention.

Exhibit 4-24. High- to low-speed transition zone area.



Source: Adapted from Torbic et al. (2012)

- **The transition zone.** Located between the rural (i.e., high-speed) and community (i.e., intermediate- or low-speed) context zones, the transition zone consists of two areas: (1) a *perception-reaction area*, where some physical and operational characteristics of the context area begin to change, conveying to the drivers an impending need to change speed and driving behavior, and (2) the *deceleration area*, where changes in the roadway, roadside characteristics, land use and access are sufficient that drivers are expected to decelerate to lower operating speeds before entering the developed area.
- **The community zone:** The community zone is the portion of roadway serving the more developed area and has different design characteristics from the other zones, including elements such as a lower speed limit, increased traffic control, on-street parking, bicycle lanes, sidewalks, curb and gutter, higher land use intensity with reduced building setbacks, frequent access points, landscaping, pedestrian and bicycle activity, raised medians, curb extensions, narrow lanes and turn lanes.

The *transition threshold*, separating the rural zone from the transition zone, is the approximate location where drivers first observe downstream signs or features that alert them to upcoming roadway context and speed changes. From a design standpoint, at the transition threshold it is best if the entire speed transition zone is visible to drivers.

The *community threshold*, separating the speed transition zone from the community zone, is where the 85th percentile operating speed should be consistent with the posted speed limit for entering the community. The community threshold should be near the edge of development for the community, and be defined by land use density, the number of access points, and changes in the roadway and roadside design. It may be appropriate to set back the community threshold a few hundred feet from the community zone, but if the community threshold is set back too far from dense development, drivers may not maintain the desired speed through the community. On the other hand, it may be necessary to set the community threshold far enough away from current development to allow for growth (Torbic et al. 2012).

4.2.11.1 Current AASHTO Policy and Guidance

The Green Book provides guidance for designing roads in high-, intermediate-, and low-speed environments; however, the Green Book provides little guidance on the design of speed transition zones. Where the Green Book provides guidance on transition design, it focuses on specific geometric elements (e.g., roadway width, lane width or number of lanes) rather than on the context and purpose of the roadway.

4.2.11.2 Speed Transition Zone Design Principles and Considerations

Each speed transition zone and community has its own unique characteristics and context. Thus, each speed transition zone must be assessed on a case-by-case basis to select appropriate treatments. Several guiding principles should be considered during the design of a high- to low-speed (or high- to intermediate-speed) transition zone. Some general principles can be assembled from existing national and international sources, including:

- *NCHRP Report 737: Design Guidance for High-Speed to Low-Speed Transition Zones for Rural Highways* (Torbic et al. 2012);
- *NCHRP Synthesis Report 412: Speed Reduction Techniques for Rural High-to-Low Speed Transitions* (Forbes 2011);
- *Speed Management* (ECMT 2006);
- *Guidelines on Traffic Calming for Towns and Villages on National Routes (REV B)* (NRA 2005);
- *Guidelines for Urban-Rural Speed Thresholds—RTS15* (LTSA 2002); and
- *Reducing Traffic Injuries Resulting from Excess and Inappropriate Speed* (ETSC 1995).

These general principles include:

- More extensive and aggressive treatments produce greater reductions in speed and crash occurrence than less extensive and passive treatments, and combinations of treatments are more effective at reducing speeds and improving safety than a single treatment;
- There should be a distinct relationship between the speed limit and the roadway and roadside characteristics;
- As the speed limit is reduced, the change in roadway and roadside characteristics should be apparent enough to reinforce the need for drivers to slow their speeds;
- Physical changes to the roadway and roadside are preferred to enforcement and education programs because they have more substantial and lasting effects;
- In the perception-reaction area of a speed transition zone, warning and/or psychological treatments (i.e., design and/or contextual elements that communicate suitable operating speed cues to drivers) are more appropriate, and in the deceleration area of a speed transition zone, physical treatments are preferred; and
- To maintain a reduction in speed downstream of the speed transition zone, additional treatments are necessary within the intermediate- or low-speed environment.

The example speed transition zone illustrated in Exhibit 4-24 is of a high-speed rural roadway transitioning to a low-speed roadway through a small rural town. Similar speed transition zones may occur in suburban and urban settings. The design principles described in this section of the Guide can apply to a variety of situations, but different types of treatments may be used to reduce speed in the differing environments.

4.2.11.3 Recommended Practice

Speed transition zones are intended to convey the need to change speeds due to a change in environment or context. To effectively encourage and reduce speeds, the following practices are recommended for the design of speed transition zones (Torbic et al. 2012, ITE 2010a):

- For changes in traveled way width, designing a geometric transition such as a lateral shift, lane addition or drop, lane or shoulder narrowing and so forth, use the established guidance in the MUTCD, in which the length of the transition taper is computed by the following equation: $L = WS^2/60$ (for speeds less than 45 mph), where L equals the length of the transition taper (ft.), W equals the width of the lateral shift or offset (ft.) and S equals the 85th percentile operating speed in mph or posted speed in mph (whichever is higher) or the target speed in new construction projects.
- When the traveled way is being widened or lanes added, a transition taper of 10:1 is normally sufficient. Speed-change lanes at intersections (transitions to left-turn or right-turn lanes) usually require a shorter taper and deceleration distance. AASHTO recommends 100 ft. for single-turn lanes and 150 ft. for dual-turn lanes.
- Traffic control devices should be used consistent with the current edition of the MUTCD (FHWA 2009b). The MUTCD should be referenced for guidance on the use of “REDUCED SPEED AHEAD” signs and stepped-down speed limits.
- Speed transition zones should desirably be designed on tangent sections of roadway to avoid horizontal and vertical sight distance constraints so the entire length of the speed transition zone is visible to drivers.
- In the context of a high-speed rural road transitioning into a built-up rural town or suburban/urban community, use of landscaping elements such as grass, shrubs, and trees that change in composition and degree of formality along the length of the transition zone is recommended to reinforce the changing characteristics of the environments.
- In the context of speed transition zones in more suburban and urban environments, roadside design features (e.g., landscaping, curbs, on-street parking, bike lanes, street light standards

with banners, entry signs, and street furniture) can serve as visual cues to influence driver speeds. Land uses, building styles and setbacks also can provide visual cues. Progressively introducing taller and closer roadside design elements to the traveled way may also reinforce the principle that altering the physical relationship between the width of the road and the height of nearby vertical elements influences a driver's perception of the appropriate speed.

- At the downstream end of the speed transition zone (i.e., community threshold), a gateway can be included. Gateways can be achieved using combinations of design features or unique intersections such as roundabouts. If sidewalks and/or bicycle lanes are not present upstream of the gateway, they should be introduced on the downstream side of the gateway, signaling the potential for increased pedestrian and bicycle activity.
- Consider reducing the overall curb-to-curb width of the street within the speed transition zone to convey the change in context. This can be accomplished by reducing the number of through lanes, reducing lane widths, dropping through lanes as turning lanes at intersections, converting through lanes to on-street parking or bicycle lanes, applying curb extensions at intersections and mid-block crossings and providing a raised median.
- Prohibit passing within the speed transition zone.

Several resources provide information on treatments that may be implemented within speed transition zones to reduce speeds and improve safety, including:

- *Transition Zone Design* (Stamatiadis et al. 2014);
- *NCHRP Report 737: Design Guidance for High-Speed to Low-Speed Transition Zones for Rural Highways* (Torbic et al. 2012);
- *NCHRP Synthesis Report 412: Speed Reduction Techniques for Rural High-to-Low Speed Transitions* (Forbes 2011);
- *Determining Effective Roadway Design Treatments for Transitioning from Rural Areas to Urban Areas on State Highways* (Dixon et al. 2008a);
- *Evaluation of Gateway and Low-Cost Traffic-Calming Treatments for Major Routes in Small Rural Communities* (Hallmark et al. 2007);
- *Main Street . . . When a Highway Runs Through It: A Handbook for Oregon Communities* (Oregon DOT 1999);
- *Engineering Countermeasures for Reducing Speeds: A Desktop Reference of Potential Effectiveness* (FHWA 2014b);
- *Speed Management: A Manual for Local Rural Road Owners* (FHWA 2012b); and
- *Speed Concepts: Informational Guide* (FHWA 2009c).

4.2.12 Intersections

Most conflicts between users of the traveled way occur at at-grade intersections, where travelers of all modes cross paths with each other. Vehicle conflicts with pedestrians or bicyclists are of greater concern given the greater vulnerability, lesser size, and variable visibility of non-motorists. Therefore, good intersection design should indicate to all modes approaching the intersection what they must do and who has to yield.

Roundabout intersections can reduce conflict potential and increasingly are being considered as alternatives to traditional at-grade intersections. Roundabouts often work well for multimodal roadways in low-speed environments. They are addressed in more detail later in this section.

The following principles apply to designing intersections for all users:

- Free-flowing movements should be avoided;
- Intersections should be designed to be as compact as possible while accommodating buses and emergency response vehicles;

- Unexpected conflicts should be avoided;
- Simple right-angle intersections are best for all users because many intersection problems are worsened at skewed and multilegged intersections;
- Access management practices should be used to remove additional vehicular conflict points near the intersection;
- Signal timing should consider the safety and convenience of all users;
- Intersection designs should integrate geographic constraints;
- Special consideration should be given in areas where users include large populations of disabled people, elderly people or children;
- Designs should encourage proper travel behavior by all users; and
- Intersections should be designed with high legibility and clarity.

4.2.12.1 *Skewed Intersections*

Generally, skewed intersections are undesirable because they introduce the following complications for all users:

- The greater travel distance across the intersection increases exposure to conflicts and lengthens signal phases for people on foot and in vehicles;
- Skewed intersections require users to crane their necks to see other approaching users, making it less likely that all users will be seen; and
- Obtuse angles encourage speeding around corners.

To alleviate problems associated with skewed intersections, design options may include:

- Designing or redesigning the intersection closer to a right angle, if possible;
- Providing pedestrian refuges if the crossing distance exceeds approximately 40 ft.;
- Marking general-use travel lanes and bike lanes with dashes to guide people on bicycles and motorists through a long, undefined area; and
- Channelizing paths of travel to maximize predictability and create space for pedestrian islands.

Redesigning an intersection to bring it closer to a right angle may require the purchase of additional right-of-way; however, the added cost may be offset by selling land that is no longer needed for the intersection back to adjoining property owners or by repurposing the unnecessary land (e.g., for a pocket park, rain garden, or greenery).

4.2.12.2 *Multileg Intersections*

Multileg intersections (intersections with more than four legs) generally are undesirable and introduce the following complications for all users:

- Multiple conflict points are added as users arrive from several directions;
- Users may have difficulty assessing all approaches to identify all possible conflicts;
- At least one leg will be skewed; and
- Users must cross more lanes of traffic and the total travel distance across the intersection is increased.

To alleviate problems associated with multileg intersections, design options may include:

- Creating a minor intersection farther upstream or downstream (which enables the removal of one or more legs from the primary intersection);
- Using roundabouts (though not necessarily mini-circles), as they are a proven safety countermeasure;
- Close one or more approach roads to motorized vehicle traffic, while still allowing access for people on foot or on bicycles;

- Creating pedestrian refuges if the crossing distance exceeds approximately 40 ft.; and
- Marking general-use travel lanes and bike lanes with dashes to guide people on bicycles and motorists through a long undefined area.

4.2.12.3 Corner Radii

An intersection's *corner radius* has a significant impact on the comfort and safety of non-motorized users. Small corner radii provide the following benefits:

- Smaller, more pedestrian-scale intersections, resulting in shorter crossing distances;
- Slower vehicular turning speeds;
- Better geometry for installing perpendicular ramps for both crosswalks at each corner; and
- Simpler, more appropriate crosswalk placement in line with the approaching sidewalks.

Normally, the smallest practical corner radii should be selected for intersection designs in areas with significant pedestrian and bicycle activity. It is helpful to keep in mind that the *actual curb radius* (the radius of the constructed curb) differs from the *effective curb radius*, which is the corner radius required for a vehicle to make a turn. Where on-street parking or bike lanes exist and curb extensions are not present, the actual curb radius may be minimized.

When designing corner radii for complete streets, a default design vehicle might be a refuse truck (representing a larger vehicle that is a regular user of the street). The design vehicle can be modeled through use of a single-unit truck. (Larger design vehicles should be used only where they are known to regularly make turns at the intersection, and corner radii should be designed based on the larger design vehicle traveling at “crawl” speed.)

Designers also should consider the effects that bike lanes and on-street parking have on the effective radius, increasing the ease with which large vehicles can turn. Under some conditions, multicentered compound curves and circular curves with tangent offsets may be useful alternatives to simple circular curve designs for corner radii.

Encroachment by large vehicles is acceptable onto multiple receiving lanes. For example, when using a design vehicle larger than a refuse truck, the vehicle should be allowed to turn into all available receiving lanes. Larger vehicles that are infrequent users of the street can be allowed to encroach on multiple departure lanes and partway into opposing traffic lanes.

Based on their review of several sources, the project research team identified several general design guidelines for corner radii, including:

- The effective curb radius should be 28 ft. to accommodate a single-unit truck (SU-30) design vehicle.
- Where parallel on-street parking or bike lanes exist, their width should be factored into the effective corner radius, and the actual curb radius should be 5 ft. to 15 ft.
- Where bus routes turn right, the design vehicle should be the typical city bus and the effective curb radius set to accommodate the turn movement.
- In industrial areas, or locations with frequent truck movement, the design vehicle should be increased to an intermediate semi-trailer (WB-50) or appropriate, and the effective curb radius should be increased to accommodate the turn movement.

The Green Book recommends that the corner radius be designed for the intersecting street type and design vehicle. Guidelines for the right-turning radii into minor side streets usually suggest that they be between 10 ft. and 15 ft. (AASHTO 2011a). Where a substantial number of pedestrians are present, the lower end of the range may be appropriate. A corner radius as low as 15 ft. also may be appropriate on arterial streets carrying heavy traffic volumes. Where buses or large trucks are prevalent, a larger curb radius should be considered.

4.2.12.4 Curb Extensions

The project team's review of multiple references and best practices suggests that, where on-street parking is allowed, curb extensions should be considered to replace the parking lane at crosswalks. Curb extensions should be the same width as the parking lane.

Bulb-outs and curb extensions should be designed with two return curves with a radius of more than 10 ft. to allow street sweepers to clean the corners. Because of reduced road width, the corner radius on a curb extension may need to be larger than if curb extensions were not installed. Curb extensions reduce pedestrian crossing distance, resulting in less exposure to vehicles and shorter pedestrian clearance intervals at signals.

4.2.12.5 Crosswalk and Ramp Placement

Crosswalks and ramps at intersections should be placed so they provide convenience and safety for people on foot (including dismounted bicyclists). The following suggested best practices identify design and operations techniques to help achieve these goals:

- To maximize pedestrian access, allow crossings on all legs of the intersection unless no pedestrian-accessible destinations exist on one or more corners;
- To reduce the amount of time that pedestrians are exposed to motorized vehicles, minimize crossing distances whenever possible;
- Add room for street furniture, landscaping and curb ramps;
- Balance the speed of turning vehicles with pedestrian safety needs;
- To allow pedestrians to walk out toward the edge of the parking lane without entering the traveled way, add curb extensions;
- Provide marked crosswalks on all legs of signalized intersections, along intersections for official school routes, on all legs of intersections in transit-oriented development districts and at other stop-controlled or uncontrolled locations where significant numbers of pedestrians cross;
- Place crosswalks as close as possible to the desired path of pedestrians (generally in line with the approaching sidewalks);
- Ensure that adequate sight lines exist between pedestrians and motorists;
- Ensure that crosswalks are not placed too far away from the intersection;
- When a raised median is present, consider extending the nose of the median past the crosswalk with a cut-through for pedestrians;
- Provide one ramp per crosswalk (two per corner for standard intersections with no closed crosswalks);
- Ensure that all ramps are entirely contained within the crosswalk, either by relocating difficult ramps or, if necessary, by flaring the crosswalk to capture a ramp that is difficult to relocate;
- Align the ramp run with the crosswalk when possible, as ramps that are angled away from the crosswalk may lead some users into the intersection; and
- Ensure consistency with the most recent adopted version of the federal ADA guidance and standards.

4.2.12.6 Intersection Grade

The Green Book notes that the gradients of intersecting roads should be as flat as practical on those sections that are to be used for storage of stopped vehicles (AASHTO 2011a). For passenger cars, the calculated stopping and acceleration distances on grades of 3 percent or less differ little from the corresponding distances on a level roadway. Accordingly, grades in excess of 3 percent should be avoided; however, where extenuating conditions exist, grades should not exceed about 6 percent.

4.2.12.7 Intersection Sight Distance

Intersection sight distance should be calculated in accordance with the Green Book using the design speed appropriate for the streets being evaluated. When executing a crossing or turning

maneuver onto a street after stopping at a stop sign, stop bar or crosswalk, drivers will move slowly forward to obtain sight distance (without intruding into the crossing travel lane), stopping a second time as necessary. Therefore, when curb extensions are used or on-street parking is in place, the vehicle can be assumed to move forward on the second stop movement, stopping just shy of the travel lane and increasing the driver's potential to see further than when stopped at the stop bar. The increased sight distance provided by the two-stop movement allows parking to be located closer to the intersection.

On-street parking should be positioned far enough away from intersections to allow for good visibility of pedestrians preparing to cross the street. The distance should be at least 20 ft. from crosswalks. One way to achieve this positioning is using curb extensions. Sightlines should be maintained to minimize conflicts between street users. Some guidelines for sightlines include:

- Maintain a minimum of 75 ft. of sightline to signal posts at signalized intersections;
- Maintain a minimum of 40 ft. of sightline at controlled mid-block crossings;
- Maintain a minimum of 40 ft. of sightline at uncontrolled crossings; and
- Maintain at least 10 ft. to 20 ft. of sightline to sidewalks for driveway users, and at least 30 ft. of sightline into the street.

4.2.12.8 Turn Lanes

The need for turn lanes for motorized vehicle mobility should be balanced with the need to manage vehicle speeds and the potential impact on multimodal facilities such as bike lanes and sidewalks. Turn lanes allow turning vehicles to move over so that through vehicles can maintain their speed.

Left-turn lanes are considered to be acceptable in an urban environment since there are negative impacts to traveled way capacity when left-turning vehicles block the through movement of vehicles. Sometimes a left-turn pocket is sufficient, without providing for vehicular deceleration, just long enough for one or two cars to wait out of through-traveling traffic.

Left-turn lanes should be considered where appropriate in an urban environment or when being used with a road diet. The number of turn lanes should be minimized and double turn lanes should be avoided where possible.

NCHRP Report 745: Left-Turn Accommodations at Unsignalized Intersections (Fitzpatrick et al. 2016) and *NCHRP Report 457: Evaluating Intersection Improvements: An Engineering Study* (Bonneson and Fontaine 2001) include guidance on where to consider a left-turn lane at unsignalized intersections.

The Green Book states that dedicated left-turn lanes should be provided where exclusive left-turn signal phasing is provided. Dedicated left-turn lanes also should be considered if the peak-hour turn volumes are greater than 100 vehicles per hour (vph). Double left-turn lanes should be considered only where the peak-hour turn volumes are greater than 300 vph (AASHTO 2011a)

Right-turn lanes can increase the crossing distance for people on foot, increase speed of through vehicles, and increase potential conflicts with people on bicycles; therefore, exclusive right-turn lanes should be used only when necessary.

Where heavy volumes of right turns exist, or high volumes of conflicting pedestrian crossing movements, a right-turn lane may be the best solution to provide additional vehicle capacity without adding additional lanes elsewhere in the intersection. For turns onto roads with only one through lane and where truck turning movements are rare, providing a small

corner radius at the right-turn lane often provides the best solution for pedestrians' safety and comfort.

Right-turn channelization islands between the through lanes and the right-turn lane can enhance pedestrian safety and access at intersections of multilane traveled ways where trucks make frequent right turns. Right-turn channelization islands also offer a good alternative to an overly large corner radius.

The following design practices for right-turn lane channelization islands should be used to provide safety and convenience for pedestrians, bicyclists, and motorists:

- Provide a yield sign for the slip lane;
- Provide a 55-degree to 60-degree angle between vehicle flows, which reduces turning speeds and improves the yielding driver's visibility of pedestrians and vehicles;
- Place the crosswalk across the right-turn lane about one car-length back from where drivers yield to traffic on the other street, allowing the yielding driver to first respond to any potential pedestrian conflict (independently of any vehicle conflict), and then move forward with no more pedestrian conflict;
- Consider installing a raised pedestrian crossing to slow vehicle turning movements and improve safety for pedestrians;
- Consider installing bollards where a raised pedestrian crossing is constructed within a channelized right-turn lane; and
- When installing bollards, place them on either side of the crosswalk, within the raised island and sidewalk and with adequate separation to maintain ADA clearance (U.S. Access Board 2011) without allowing sufficient space for a car to travel through.

A channelized island should be designed roughly twice as long as it is wide. The corner radius will typically have a long radius (150 ft. to 300 ft.) followed by a short radius (20 ft. to 50 ft.). When creating this design, it is necessary to allow large trucks to turn into multiple receiving lanes. Often, this design is not practical for right-turn lanes onto roads with only one through lane. This right-turn channelization design is different from designs that provide free-flow movements (through a slip lane) where right-turning motorists turn into an exclusive receiving lane at high speed. Right turns could be signal-controlled in this situation to provide for a signalized pedestrian walk phase. A raised pedestrian crosswalk could also be used to slow vehicles down and make pedestrians more visible.

NCHRP Report 457: Evaluating Intersection Improvements: An Engineering Study Guide (Bonneson and Fontaine 2001) includes guidance on where to consider a right-turn lane at unsignalized intersections. Guidance from *Designing Walkable Urban Thoroughfares: A Context Sensitive Approach* (ITE 2010a) states that a right-turning volume of 200–300 vph is an acceptable range for the provision of right-turn lanes at signalized intersections.

The Green Book (AASHTO 2011a) provides guidance on the design of components associated with an auxiliary, median or turn lane. When designing a turn lane, it is necessary to consider the necessary storage, deceleration and taper lengths. The deceleration length is a function of the brake-reaction distance and the distance required for the approaching vehicle to come to a stop. It is common practice to accept a moderate amount of deceleration within the through lanes and to consider the taper length as part of the deceleration within the through lanes. On urban or low-speed roadways, deceleration lengths are not always needed, as the deceleration of the turning vehicles helps control the speed of through-traveling traffic.

The length of the turn lane should be sufficient to store the number of vehicles (or queue) likely to accumulate during a crucial period. On urban roads, where space is limited, a minimum 50-ft. storage distance should be provided to accommodate two vehicles. Where a high percentage of buses or trucks are expected, this length should be increased.

The applicable taper design is a function of the design speed and roadway geometrics. For urban areas, short tapers are preferred because they provided more vehicle queue space and are not as crucial for slow vehicle speeds during peak periods.

4.2.12.9 Intersection Controls

Two-way stops and *yield* intersections are the most common forms of controlled intersections. In low-volume areas, however, stop signs can create unnecessary delays by forcing drivers on the minor approach to stop even when no conflicting vehicle exists. Drivers may, as a result, begin to disregard the stop sign, creating potential for crashes or collisions when approaching vehicles are not seen. Yield signs are an alternative to stop signs and may be appropriate when some level of right-of-way assignment is desired but sight distance is adequate for yield conditions. Mini-roundabouts may also be considered as an alternative intersection control measure; mini-roundabouts keep speeds low along both approaches and provide additional opportunity for landscaping.

All-way stops are used where equal volumes of traffic exist along intersecting approaches. All-way stops often are used as an interim measure before an intersection is signalized. Where possible, mini-roundabouts or traffic circles should be considered as an alternative intersection control to allow conflicting side street vehicle movements to occur concurrently with reduced delay.

Signalized intersections provide unique challenges and opportunities for livable communities and multimodal design. On one hand, signals provide control of people on foot and motorized vehicles with numerous benefits. Where signalized intersections are closely spaced, signals can control vehicle speeds by providing appropriate signal progression along a corridor. Traffic signals can reduce conflicts with motorized vehicle traffic when pedestrians or people on bicycles cross major streets, but their operation also can create challenges for non-motorized users. Signalized intersections often have significant vehicular turning volumes, which can conflict with concurrent movements of pedestrians and people on bicycles if not properly addressed through signal phasing and timing. In many situations, roundabouts may offer a safer, more convenient intersection treatment for multimodal accommodation than traffic signals.

To improve livability and pedestrian/bicycle safety, signalized intersections should:

- Provide signal progression at speeds that support the target speed of a corridor whenever feasible;
- Provide short signal cycle lengths, which allow frequent opportunities to cross major traveled ways, improving the usability and livability of the surrounding area for all modes;
- Ensure that signals detect bicycles;
- Place pedestrian signal heads in visible locations;
- Time the pedestrian phase to be on automatic recall at locations and/or times that experience high foot traffic (e.g., central business districts, transit areas, and near schools at certain times of day);
- Set signal timing to favor uninterrupted travel for people on bicycles or those using bus transit; and
- Where few pedestrians are expected and automatic recall of walk signals is not desirable, place pedestrian pushbuttons in convenient locations per the MUTCD (FHWA 2009b).

4.2.12.10 Roundabouts

Roundabouts should generally be considered the first traffic control option at otherwise controlled intersections. Roundabouts reduce vehicle-to-vehicle and vehicle-to-pedestrian conflicts and, because they reduce vehicle speed, also reduce all forms of crashes and crash severity. In

particular, roundabouts eliminate left-turn and right-angle crashes, which are common crashes at signalized intersections.

Other benefits of roundabouts include:

- Reduced delay, travel time, and vehicle queue lengths;
- Facilitated U-turns;
- Improved accessibility to intersections for people on bicycles through reduced conflicts and vehicle speeds;
- Options for people on bicycles of differing abilities to navigate the roundabout;
- Reduced maintenance and operational costs (primarily maintenance of landscaping and litter control);
- A smaller carbon footprint, as no electricity is required for operation and vehicles use less fuel because they spend less time idling and do not have to accelerate as often from a dead stop;
- The opportunity to reduce the number of vehicle lanes between intersections (e.g., to reduce a five-lane road to a two-lane road, due to increased vehicle capacity at intersections);
- Little to no delay for pedestrians who have to cross only one direction of traffic at a time and do not need to wait for a specific pedestrian crossing phase;
- Lowered noise levels;
- The central island can vary in shape from a circle to a “square-a-bout” (e.g., in historic areas), ellipses at odd-shaped intersections, dumbbell, or even peanut shapes; and,
- The ability to create a gateway or transition between distinct areas.

Single-lane roundabouts can vary in size, with central island diameters from 12 ft. to 90 ft. to fit a wide range of intersections and accommodate through movements and different turn movements by various design vehicles. As such, they can be used at a large number of intersections to achieve various objectives.

Some single-lane roundabouts are constructed to accommodate through movements by large articulated trucks, but do not permit the trucks to make turn movements. However, they do normally accommodate turn movements by single-unit trucks such as ladder trucks and garbage trucks.

Pedestrian crossings are improved through the inclusion of splitter islands and slow speed approaches by vehicles. People on bicycles are able to navigate the roundabout by taking the lane or accessing the sidewalk through a ramp.

Multilane roundabouts can be considered when single-lane roundabouts are inadequate for the traffic volume. Consideration should be given to using roundabouts that have two through lanes on the major street and a single lane on the minor street (with or without additional turn lanes) before automatically designing a full multilane roundabout. Because these multilane roundabouts are larger than single-lane roundabouts, they often accommodate all turn movements by most large vehicles. It is still necessary to confirm the size and movements by the design vehicle(s), however, because these roundabouts often have to accommodate larger trucks or special vehicles.

Multilane roundabouts provide bicyclists the option to take the lane or divert onto the sidewalk through a ramp. To improve pedestrian safety when crossing the multiple approach lanes, additional treatments can be provided (e.g., pedestrian-actuated RRFs).

Mini-roundabouts have traversable islands and yield control on all approaches, which allows them to function similarly to other roundabouts (FHWA 2013e). They should not be confused with neighborhood traffic circles. Mini-roundabouts are used in low-speed urban environments, where operating speeds are 30 mph or lower and right-of-way constraints preclude the use of a standard roundabout. The design is based on passenger vehicles passing through the roundabout

without traveling over the central island. To accommodate large vehicles, mini-roundabouts can be designed to include a traversable central island and traversable splitter islands.

Neighborhood traffic circles are very small circles that are retrofitted into local street intersections to control vehicle speeds, calming traffic on low-volume neighborhood streets. Mini-circles also may be installed in neighborhoods for aesthetic purposes (FHWA 2013e). Typically, landscaping and/or a tree will be located within the central island to provide increased visibility of the traffic circle and enhance the intersection.

Neighborhood traffic circles should generally have similar features as roundabouts, including yield-on-entry signage and painted or mountable splitter islands. Larger vehicles can turn left in front of the central island. The design of neighborhood traffic circles is primarily confined to selecting a central island size to achieve the appropriate design speed of approximately 15 to 18 mph (Rodegerdts et al. 2010).

Refer to *NCHRP Report 672: Roundabouts: An Informational Guide*, 2d Ed. (Rodegerdts et al. 2010) for roundabout design guidance.

4.3 Other Design Considerations for All Users in Traveled Way Design

Several considerations in roadway design are not cross section elements but may be important to the design process, depending on community goals, context relationships, operational and safety considerations, geography, climate and other factors. Those considerations include:

- Speed management;
- Access management;
- Snow removal and storage;
- Stormwater management;
- Special roadway designs (e.g., road diets, main streets or shared streets);
- One-way streets;
- Bridges;
- Railroad-highway grade crossings;
- Fire and emergency medical services; and
- Traffic control devices and operations.

4.3.1 Speed Management

Research has shown that higher operating speeds result in higher crash severity, including higher percentages of injury and fatality crashes and more serious property damage. Pedestrians and bicyclists are particularly vulnerable in the event of a crash. Speed is of fundamental importance: the severity of a pedestrian injury in the event of a crash is directly related to the speed of the vehicle at the point of impact. For example, a pedestrian who is hit by a motorized vehicle traveling at 20 mph has a 95 percent chance of survival, whereas a pedestrian hit by a motorized vehicle traveling at 40 mph has a 15 percent chance of survival (Limpert 1994). In addition, vehicles traveling at lower speeds have more reaction time, which helps prevent crashes. Designing for reduced vehicle speeds is especially important in urban, urban core and rural town contexts with higher levels of pedestrians and bicyclists.

Speed management is an approach to controlling speeds using enforcement, design and technology applications. Although this Guide primarily addresses guidance for the design of streets and roadways, the design of a roadway facility should be closely aligned with its subsequent goals for operation and maintenance. To reinforce the relationship between the geometric design of

a street or road and its resultant operating speed, in October 2015 FHWA issued a memorandum titled *Relationship Between Design Speed and Posted Speed*, which provides this guidance: “In urban areas, the design of the street should generally be such that it limits the maximum speed at which drivers can operate comfortably, as needed to balance the needs of all users” (FHWA 2015c).

Traffic calming is a type of speed management that is usually associated with local residential streets, but speed management methods can be used on all types of roadways. Speed management methods can use technologies that provide feedback to the motorist about their speed, or designs in which the motorist perceives the need for a lower speed. These techniques include signage, signalization, enforcement, street designs and built environments that encourage slower speeds. Other methods include physical devices that force drivers to slow down, such as roundabouts, raised intersections or narrowed sections created by curb extensions and raised medians. Physical devices generally are more effective at changing driver behavior, but they may be more costly to implement and may not be appropriate on all roadways.

The design decision to employ a speed management program often requires a multidisciplinary process, as this approach affects several groups of users and adjacent property owners. Developing the program requires input from engineering, emergency services, bicycle and pedestrian advocacy groups, street maintenance providers, law enforcement and transit service providers. Public involvement helps the design team understand how the community uses roadways and how it perceives various speed management methods. Designing a facility to achieve desired speed results requires knowledge of the existing traffic patterns for all users, including both quantitative and qualitative information. Ideally, speed management should be a consideration in all projects serving multiple modes, regardless of the functional classification of the roadway. It is important for a corridor to have appropriate operating speeds within the project limits and through different jurisdictions if the character and context also remain constant.

The following lists present “active” (generally physical design features) and “passive” (generally operational and psychological techniques) speed management measures commonly used in the United States on low- and intermediate-speed roadways functionally designated as arterials or collectors. Not all techniques are considered appropriate across all contexts and speed ranges.

4.3.1.1 Active Measures

Commonly used active speed management measures include:

- Roundabouts, particularly when used within a “roundabout corridor”;
- Road diets (reducing the number of lanes by adding medians, converting travel lanes to parking, or adding bike lanes);
- Narrowed travel lanes;
- Center raised island;
- Mid-block neck-downs (narrowing the traveled way using curb extensions, possibly with a center island);
- Chicanes (lateral shift design techniques that require vehicles to move out of a straight path);
- Smaller curb return radii to slow turning vehicles and the elimination of free-flow channelized right-turn lanes;
- Provision of on-street parking where adjacent land uses and activities will generate demand;
- Speed tables or humps (not typically used on roadways with speeds above 30 mph; may impact emergency service response routes and times);
- Speed cushions or speed platforms (less impact on emergency vehicles than humps and tables);
- Raised crosswalks combined with curb extensions to narrow street; and
- Speed-actuated traffic signals where a vehicle traveling at excessive speeds will actuate the signal to change to red.

4.3.1.2 Passive Measures

Commonly used passive speed management measures include:

- Synchronized signals to create progression at an appropriate speed;
- Radar trailers/speed feedback signs flashing “SLOW DOWN” message when speed exceeds a preset limit (most effective when coupled with enforcement);
- Visually narrowing road using pavement markings;
- Visually enclosing street with buildings, landscaping and street trees;
- Variable speed limits (using changeable message signs based on conditions);
- Speed enforcement corridors combined with public education;
- Flashing beacons on intersection approaches to slow traffic through the intersection;
- Speed limit markings on pavement;
- Mountable cobblestone medians or flush concrete bands delineating travel lanes for visual narrowing;
- Shared routes using signs and pavement markings (such as bicycle boulevards); and
- Automated speed enforcement (including red light enforcement).

These speed management measures may be implemented in the design of new facilities, reconstruction, resurfacing and restriping projects. Every design project offers opportunities to implement new design features that may help manage operating speeds to desired values. Additional detailed guidance for some of the more common design elements used for speed management include:

- **Mid-block neck-downs.** Roadway geometry can be altered at mid-block locations to reduce motorized vehicle speeds by diverting the driver’s path of travel. Neck-downs are curb extensions on opposite sides of the road, which create a “pinch-point.” They are particularly useful on streets with longer block lengths where motorists tend to pick up speed. They can be combined with mid-block pedestrian crossings to enhance pedestrian safety further by reducing crossing distances and increasing visibility. Recommendations for the use of neck-downs include:
 - Mid-block neck-downs can be used on two-way streets with one lane in each direction, and one-way roads with no more than two lanes. They are sometimes combined with intermittent medians to reduce speeds along the length of a roadway.
 - Vegetation used in the neck-down should generally be low growing and low maintenance.
 - In locations with mid-block pedestrian crossings, sight distances should be maintained.
 Design considerations for mid-block neck-downs include:
 - Where neck-downs provide pedestrian crossings, ADA-compliant curb ramps, tactile warning strips, and cross slopes should be provided; consider other traffic-calming elements such as raised crossings.
 - Mid-block neck-downs can serve as alternatives to speed tables.
 - Care should be taken to avoid suddenly squeezing bicyclists into the traffic flow on streets with higher volumes of traffic, particularly in locations with steep uphill grades where bicyclists may be traveling considerably slower than motorized vehicle traffic.
 - On low-volume, low-speed residential streets, neck-downs can reduce the street to one lane, requiring oncoming drivers to alternate passage through the neck-down, while maintaining enough clear space for fire trucks and other large vehicles.
 - Designs should consider snow removal operations in snow regions. Mid-block neck-downs offer space to store snow in winter; however, visual cues should alert snowplow operators of the change in the roadway.
- **Chicanes.** A chicane is a design feature that creates “S” curves in the roadway travel paths that drivers must weave through, with the effect of slowing speeds. Chicanes can be created by alternating parking from one side of the roadway to the other, as well as through curb extensions.

Chicanes provide opportunities to increase sidewalk space and introduce landscaping and green street elements in the right-of-way. Recommendations for their use include:

- Chicanes can be used on two-way streets with one lane in each direction, and one-way roads with no more than two lanes.
- The amount of horizontal deflection should be based on the proposed design speed of the roadway.
- Vegetation used in chicanes should generally be low growing and low maintenance. In locations with mid-block pedestrian crossings, sight distances must be maintained.

Design considerations for chicanes include:

- Care should be taken to maintain space for bicyclists and to avoid suddenly squeezing bicyclists into the traffic flow on streets with higher volumes of traffic, particularly in locations with steep uphill grades where bicyclists may be traveling considerably slower than motorized vehicle traffic.
- Designs should consider snow removal operations. Chicanes offer space to store snow in winter; however, visual cues should alert snowplow operators of the change in the roadway.
- Chicanes can serve as alternatives to speed tables.
- **Center raised islands.** A center island can be used to narrow the roadway, reduce motorized vehicle speeds, and improve pedestrian crossings. Center islands also provide opportunities to introduce green elements in the right-of-way, and can be used to absorb stormwater and reduce the heat island effect. Recommendations for their use include:

- Center islands with crosswalks and pedestrian refuges improve pedestrian safety and access by reducing crossing distances and enabling pedestrians to cross roadways in two stages. Islands with crossings should be designed with a stagger, or a “z” pattern, forcing pedestrians to face oncoming traffic before progressing through the second phase of the crossing. Center islands with crosswalks should meet all accessibility requirements.
- Center islands can reduce the risk of head-on collisions and limit left-turn opportunities to desirable locations (e.g., signalized intersections).
- Center islands should be carefully designed to ensure proper drainage and maximize the potential for on-site stormwater retention and infiltration.

Design considerations for center islands include:

- Sidewalks should not be reduced in width and bicycle lanes should not be eliminated to provide space or additional width for islands.
- Center islands can be combined with mid-block pedestrian crossings to reduce crossing distances.
- Permeable surfaces, street trees, and low-growing (less than 3 ft. at mature height including the height of the curb and earthwork), drought-resistant plant materials should be used wherever safe and feasible.
- Plants should be located as far from the curb as possible to prevent exposure to salt and sand in snow regions.
- Center islands should be at least 6 ft. wide when used for low plantings, 10 ft. wide for columnar trees and 18 ft. wide for larger shade trees.
- Designs should consider snow removal operations. Center islands offer space to store snow in winter; however, visual cues should alert snowplow operators of the change in the roadway.
- **Speed tables.** Speed tables are raised pavement areas that are placed at mid-block locations to reduce vehicle speeds. Speed tables are elongated and have been shown to effectively reduce 85th percentile speeds. Well-designed speed tables enable vehicles to proceed comfortably over the device at the intended speed, but cause discomfort when traversed at inappropriately high speeds. Recommendations for the use of speed tables include:
 - Speed tables are typically 3 in. higher than the roadway surface and 3 in. below the top of the curb, but can be fully raised 6 in. to the height of the curb.

- Generally, speed table design provides 22 ft. of length, with 6-ft. ramps and a 10-ft. flat section along the top. They normally extend the full width of the roadway, although sometimes they are tapered at the edges to accommodate drainage patterns.
- Speed tables should be designed with a parabolic profile or a flat top, with consideration for a smooth transition for bicyclists.
- Per the MUTCD, speed tables should be clearly marked with reflective pavement markings to alert motorists and bicyclists of their presence and they can adjust their speed accordingly.

Design considerations for speed tables include:

- Speed tables should not be confused with speed bumps. Speed bumps are typically only 1–3 ft. wide and used in parking lots and are NOT recommended for public streets.
- Speed tables 22 ft. in length have a design speed of 25 mph to 30 mph and are easier for large vehicles to negotiate.
- Avoid placing speed tables at the bottom of steep inclines where bicyclists travel at higher speeds and may be surprised by their presence.
- Speed tables should be utilized in series or supplemented with other traffic-calming measures to effectively reduce travel speeds throughout a corridor or neighborhood. When used alone, speed tables may otherwise result in speed spiking, or when motorists travel at higher speeds between tables.
- Designs should consider snow removal operations where appropriate. Visual cues should alert snowplow operators of the change in the roadway.
- **Pavement treatments.** The choice of roadway materials can have significant impacts on traffic safety and speeds, user comfort, vehicle maintenance costs, stormwater management, roadway noise and the heat island effect. Paving treatments include colored pavements and stamped concrete or asphalt. Paving treatments can help reduce speeds and are more commonly used on streets with high volumes of pedestrians and lower volumes of motorized vehicle traffic, such as shopping districts and main streets. Modern textured pavements are smoother than cobblestones, which helps accommodate bicyclists. Regardless of the material used on the roadway, an accessible and smooth travel path must be provided at crosswalks to accommodate persons with disabilities. Guidance for the use of pavement treatments includes:
 - Concrete is discouraged where frequent utility cuts are likely and must have joints to allow for expansion;
 - Pavers should generally not be used in roadway construction except for specially designated low-speed streets;
 - Care should also be taken to ensure that materials do not settle to different heights;
 - The use of paving treatments in parking lanes can visually reduce the width of the roadway;
 - Pedestrian crossings must meet accessibility requirements by providing a smooth, stable and slip-resistant accessible path, and should include the necessary reflective markings as required in the MUTCD;
 - Pavers should not be used in crosswalks; and
 - The use of colored pavements for traffic control purposes (i.e., to communicate a regulatory, warning, guidance message) is narrowly defined by the MUTCD, and may be required to follow FHWA's experimentation process.

Design considerations for pavement treatments include:

- Key considerations for the selection of pavement materials include constructability, ease-of-maintenance, smoothness, durability, porosity and color;
- Consideration also should be given to the street type, the volumes and types of users (i.e., pedestrians, heavy vehicles, bicyclists), adjacent land uses and stormwater management goals;
- Textured pavements are usually an expensive treatment and include long-term maintenance responsibilities;

- Consider the reflective characteristics of the pavement; high albedo pavements absorb less heat;
- Surfaces such as smooth granite, tile or brick should not be used because they create slippery conditions for bicyclists and pedestrians in wet weather;
- Pavements that resist heaving and rutting should be used for locations where heavy vehicles stand or park, or at locations that are particularly susceptible to wear (e.g., high-volume intersections or steep grades); and
- Concrete bus pads should be considered on high-frequency bus routes.

As mentioned in this Guide under “Traveled Way Transition Design,” several documents provide detailed guidance on the selection and use of various design and operations techniques for managing speeds on streets and roads to improve safety and benefit vulnerable users such as pedestrians and bicyclists. Important information from these sources includes the following:

- ***Engineering Countermeasures for Reducing Speeds: A Desktop Reference of Potential Effectiveness* (FHWA 2014b).** This publication provides the results of a wide range of design elements and operational features proven to reduce speeds in certain settings. Supported by 54 reference studies, the countermeasure areas include geometric features, surface treatments and markings, signs, narrowing, access controls, and combination measures.
- ***Speed Management: A Manual for Local Rural Road Owners* (FHWA 2012b).** This manual provides information on how to develop a speed management program that is tailored to meet the needs of local rural road practitioners. This document describes the various elements of a speed management program, including the principles of setting speed limits appropriate for roads within the jurisdiction and various countermeasures that are effective in mitigating speeding as it relates to roadway safety in rural areas. The manual addresses engineering, education and enforcement strategies. It also provides more specific guidance on traffic control elements, street and road design elements, traffic-calming techniques and gateway design treatments.
- ***Speed Concepts: Informational Guide* (FHWA 2009c).** The informational guide discusses how the speed at which drivers operate their vehicles directly affects two performance measures of the highway system: mobility and safety. Noting that higher speeds provide for lower travel times and therefore good mobility, this FHWA guide observes that the relationship of speed to safety is not as clear cut. The document also recognizes that the risk of injuries and fatalities increases with speed. Designers of streets and roadways use a designated design speed to establish design features and operators set speed limits deemed safe for the particular type of road; but drivers select their speed based on their individual perception of safety. This guide discusses the concepts of designated design speed, operating speed, and the speed limit and introduces a new concept, *inferred design speed*. It explains how these elements of speed are determined and how they relate to each other. The publication is intended to help engineers, planners and elected officials better understand design speed and its implications in achieving desired operating speeds and setting rational speed limits.

4.3.2 Access Management

Access management is the practice of properly locating, designing and operating access to adjoining properties to reduce conflicts and improve safety while maintaining reasonable property access and traffic flow on the public street system. This section of the Guide addresses only private driveway access to roads and streets.

Driveways, especially busy commercial driveways, can have a significant impact on the adjacent roadway. Good driveway design should facilitate smooth vehicle egress and ingress to and from the roadway and should provide for safe accommodation of pedestrians and bicyclists.

Driveway design should consider the roadway functional classification and driveway usage to better accommodate varying roadway contexts, community needs, and existing conditions.

In conjunction with the PROWAG (U.S. Access Board 2011), the ADAAG (U.S. Access Board 2002) and the *Revised Draft Guidelines for Accessible Public Rights-of-Way* (U.S. Access Board 2005) provide specific suggested guidelines for elements such as minimum width, cross slope, grade and edge conditions at the intersection of sidewalks and driveways to be ADA compliant. These guidelines are based on pedestrian needs and do not comprehensively address safe and efficient vehicle movements at driveways. Recommendations are needed to accommodate accessibility concerns as well as safe and efficient vehicle use of the driveway.

NCHRP Report 659: Guide for the Geometric Design of Driveways was developed to provide recommendations for the geometric design of driveways that consider standard engineering practice and accessibility needs and provide for safe and efficient travel by motorists, pedestrians, and bicyclists on the affected roadway (Gattis et al. 2010). This guide contains significant detailed guidance on the design of driveways that consider all users, especially those in urban and suburban context areas.

4.3.2.1 Attributes of Bicyclists, Drivers, and Pedestrians (NCHRP 659)

The abilities and limitations of the people using the driveway as bicyclists, drivers and pedestrians will affect design choices. Appreciation of the concept of driver workload leads to the objective of trying to limit the number of (1) decisions a driver must make and (2) potential conflicts with different streams of traffic. Acknowledging that rain, fog and nighttime conditions can make physical objects more difficult to detect, a designer tries to create well-defined edges and increase the contrast between various surfaces (e.g., between the driveway opening and the border area). The AASHTO guides for the design of highways and streets, bicycle facilities, and pedestrian facilities provide a discussion of user characteristics (AASHTO 2011a, AASHTO 2014b, AASHTO 2004b). *Characteristics of Emerging Road and Trail Users and Their Safety* provides data for a wide range of users, including bicyclists and pedestrians (FHWA 2004).

Pedestrians on sidewalks routinely cross driveways, particularly in urban, suburban and rural town contexts where pedestrians and bicyclists are most prevalent. *TCRP Report 112/NCHRP Report 562: Improving Pedestrian Safety at Unsignalized Crossings* (Fitzpatrick et al. 2006) provides a distribution of the walking speeds of pedestrians under age 60 and over age 60. In both age groups, most pedestrians walk at speeds between 3 ft. and 6 ft. per second.

When estimating the time required for a pedestrian to cross the driveway, the designer should make an allowance for the pedestrian who is not starting from the exact edge of the driveway. A pedestrian may be standing 2 ft. or more back from the driveway edge when the pedestrian begins to walk across the driveway, and if groups of pedestrians exist, the starting distance for some people in the group may be even farther back from the curb.

Bicyclists also cross the paths of vehicles entering and leaving driveways. On shared-use paths, a design speed of at least 20 mph is typically assumed because speeds above that would not be desirable in a shared-use setting. Grade and wind also can affect the speeds of bicyclists, with downgrades creating speeds closer to 30 mph. The *Urban Street Geometric Design Handbook* notes that most bicyclists in mixed-use settings tend to travel within a range of 7 mph to 15 mph, with an average of 10 mph to 11 mph (ITE 2009b). *Characteristics of Emerging Road and Trail Users and Their Safety* has examined characteristics of a wide range of users, finding that the 85th percentile speed for bicycles is 14 mph, and that for recumbent bicycles is 18 mph.

General design considerations for driveways include:

- The number of driveways should be minimized (i.e., consolidated whenever possible) to reduce the number of conflict points for pedestrians and bicyclists and also benefit motorists' safety;
- Driveways should normally be designed to look like private driveways, not public street intersections;
- Driveways should be located away from intersections;
- Driveways should be kept as narrow as possible to minimize exposure to vehicles;
- Well-defined driveways clearly mark the area where motorists will be crossing the pedestrians and bicyclists path;
- Non-defined vehicle access points with continuous access to parking create a long potential conflict area between pedestrians and motorists, and this added area of ambiguity complicates the motorist's task of watching for these vulnerable users;
- Sidewalks and bicycle facilities behind the curb should clearly continue through the driveway approach; and
- The level of the sidewalk should be maintained, and the driveway should be sloped so that the motorist goes up and over the sidewalk.

It bears noting that maintaining the level of the sidewalk and sloping the driveway helps with several goals: meeting ADA accessibility requirements will be easier; the fact that the pedestrian has the right-of-way will be clear; and motorists will need to slow down slightly to enter the driveway, which will help improve crossing safety.

The following access management approaches can help improve pedestrian and bicyclist safety as well as mobility at access points in the vicinity of signalized and unsignalized urban and suburban intersections:

- Provide raised medians on the major roadway to prohibit vehicles from turning left into driveways, thus reducing the number of pedestrian-vehicle conflicts at the driveways;
- Construct a channelized island between the inbound and outbound movements at right-turn-only driveways to provide a pedestrian refuge across the driveway;
- Minimize the width of the driveway as much as possible to reduce pedestrian crossing distances (i.e., reduce exposure);
- Place sidewalks and pedestrian driveway crossings so that pedestrians are visible to the drivers, and drivers are visible to the pedestrians;
- Do not block pedestrian-driver sightlines with landscaping or signage;
- Include bike lanes and signage, as appropriate, to alert bicyclists that motorists may be entering or exiting a driveway and to alert motorists that bicyclists may be crossing the driveway;
- Use colored pavement across driveways in combination with crosswalk markings and audio/visual treatments (e.g., a signal and/or flashing sign that is activated to alert pedestrians a vehicle is about to cross the sidewalk from an adjacent parking area) for exiting vehicles with limited sight distance;
- Restrict inbound vehicle speeds by designing the driveway access with appropriately designed radii; and
- Take care to balance vehicle and pedestrian safety: Smaller driveway radii of 25 ft. to 35 ft. are more sensitive to pedestrian movements because motorists must slow down to complete the turn; however, on-street parking and bike lanes can increase the effective driveway radius.

4.3.3 Snow Removal and Storage

During and after a snowstorm, most snowplows operate in emergency or "hurry-up" mode, focusing on opening up lanes for vehicles. Often, snow is pushed from the vehicular

lanes, into bicycle lanes, parking lanes or along the sidewalks, thus making it difficult for bicyclists and pedestrians to use the facilities that have been provided for them. Snow and ice blockages can force pedestrians onto the street at a time when walking in the roadway is particularly treacherous. Adding to the problem, piled snow can create sight distance restrictions.

Many localities that experience regular snowfalls have enacted legislation requiring homeowners and businesses to clear the sidewalks fronting their property within a reasonable time after a snowfall occurs. In addition, many public works agencies have adopted snow removal programs that ensure that the most heavily used pedestrian routes (including bus stops and curb ramps at street crossings) are cleared so that snow plows do not create impassable ridges of snow. In some states, snowplow operations clear the entire roadway from curb to curb. After the roadway is cleared, a smaller “snow blow” crew (using equipment such as snow blowers, brushes, pickups and plows) clears pedestrian facilities.

In areas that receive regular snow, there will be trade-offs between the recommendations of this report and the efficiency of snowplowing. Some recommended design elements, such as curb extensions and on-street parking, will affect snowplowing operations. These trade-offs need to be clearly communicated in the design process. Moreover, early collaboration with officials in charge of snow removal is imperative for a successful design.

4.3.3.1 Recommended Practices for Snow Removal

The following practices are recommended regarding provisions for snow removal in the design of low- and intermediate-speed roadways that serve all users:

- Design street-sides to accommodate a normal level of plowed snow behind the curb without blocking pedestrian or bicycle throughways (e.g., by using a wide planting strip or furnishings zone that can accommodate plowed snow);
- Design the furnishings zone to minimize the use of objects that interfere with the ability to plow snow onto the street-side (e.g., large raised planters, continuous hedges and large utility and traffic control cabinets);
- Keep in mind that plowed snow can wrap around objects including trees, signs and light poles; and
- Use hardscape or setbacks that place plantings and trees beyond the anticipated plow line to reduce landscape damage from deicing chemicals.

4.3.4 Stormwater Management

Proper management of stormwater on multimodal urban and suburban roadways improves the walking and bicycling environment, aesthetics and community quality. Green stormwater management practices add value and multiple functionality and should be considered in roadway improvement projects.

Traditionally, stormwater runoff from roadways and roadsides normally must be collected and transported within the right-of-way; however, not all communities treat stormwater the same way. In some communities, the convention is to collect and carry stormwater runoff via networks of storm sewer pipes that bring it to a treatment plant, which then sends it as an outfall into a water body or possibly to another facility for beneficial reuse. Other communities control stormwater at the source or through roadside treatment control “best management practices” (BMPs). In this Guide, stormwater treatments that use the traveled way are discussed in this section; the use of BMPs is addressed in Chapter 5, Roadside Design Guidelines.

4.3.4.1 Stormwater Drainage Inlet Design

On many roads, stormwater drainage design typically involves a curb and gutter and drainage grates that occur on the right edge of the road, creating potential conflicts with bicyclists. The most effective way to avoid drainage grate problems for bicycles is to eliminate them entirely by using inlets in the curb face. Using alternatives to curb and gutter design can provide the same function as standard gutters and grates while not posing an impediment to bicyclists. Where grates are used, however, the following practices will reduce their impact on bicycling safety:

- **Design considerations.** The function of drainage grates is to drain stormwater quickly from the roadway and to provide access to maintenance workers to clean out the inlet. The gutter and grate (or inlet) must be hydraulically effective. Gutters are sloped to direct water flow into the inlet. This keeps water from ponding at the longitudinal joint and undermining the pavement. Gutters also protect the curb from being damaged during maintenance and resurfacing. Grates may be rendered useless, however, if they become clogged with debris (e.g., in areas with many deciduous trees). Generally accepted best practices suggest that a clogging factor of at least 50 percent should be assumed for city streets in the absence of local data.
- **Grateless roadway designs.** Curb-face opening inlet designs can be an effective substitute for grates, particularly on roadways with grades of less than 3 percent. For hydraulic efficiency, a depression of approximately 1 in. is needed in the vicinity of the curb-face inlet; this depression should occur gradually so that it does not pose an obstacle to bicyclists. Maintenance access can be placed in back of the curb (on the sidewalk side). Where curb-face inlets cannot be built, slotted linear drain inlets can be used in the shoulder area in lieu of the grate inlets.
- **Design and placement of drainage grates.** Attempts have been made to retrofit bicycle-unsafe grates by welding crossbars onto the parallel bars, but this solution usually is unsatisfactory, and it costs more than initially installing correctly designed grates. Optimally, the roadway should be designed so that the bicyclist does not have to traverse the grate. On roadways with curb and gutter, the grate should not be wider than the gutter pan. If the gutter pan needs to be widened to accommodate a large drainage grate, the taper should be on the outside edge into the planter strip.

On roads with bike lanes, the roadway should be designed such that the minimum bicycle lane width of 4 ft. is ideally maintained between the bike lane stripe and the edge of the gutter, or to the face of curb in constrained settings. If 4 ft. cannot be maintained, then a curb-face inlet design for the drainage grate should be considered.

On roadways with shoulders, the grate should be placed outside the travel path of the bicyclist (i.e., 4 ft. of clear pavement should be maintained between the shoulder stripe and the left edge of the drainage grate). If 4 ft. cannot be provided within the existing shoulder width, the shoulder can be widened to accommodate the grate, with the taper on the outside edge, or a narrower grate should be selected. Optimally a 12-in. maximum gutter pan should be used on new construction projects.

4.3.5 Utility Facilities

Utility facilities normally are placed in the roadside whenever possible. In many urban and suburban communities, however, the roadside has limited room for utility placement and access, so utilities are placed under the traveled way with numerous utility access points.

Utility covers and construction plates can be slippery, and they create changes in surface elevation with the surrounding pavement that present obstacles to bicyclists in both vehicle and bicycle lanes. Covers and plates can be replaced with less-slippery designs or materials, but to minimize their adverse impacts on bicyclists, it is best to design the roadway to locate covers and plates outside the typical path of bicyclists riding on the roadway. Wherever possible, street and road designs should not place manhole and other utility plates and covers where bicyclists

typically ride (i.e., within the 6 ft. adjacent to the curb, or between 7 and 12.5 ft. from the curb if parking is permitted).

Plain steel plates are slippery and should not be used for permanent installation on the roadway. Temporary installations of construction plates on the roadway should endeavor to avoid using plain steel plates if possible. Manufacturers may imprint waffle-shaped patterns or right-angle undulations on the surfaces of steel or concrete covers and plates to achieve an acceptable level of skid resistance. The maximum vertical deviation within the pattern should be 0.25 in., and, if possible, the placement of the construction plates should provide a clear zone for cyclists to avoid the plates.

4.3.6 Special Roadway Design Concepts

This section discusses the design of three specialized types of roadway designs: road diets, main streets and shared streets.

4.3.6.1 Road Diets

Road diets involve the reconfiguration of one or more travel lanes to calm traffic and provide space for bicycle lanes, turn lanes, streetscapes, wider sidewalks, on-street parking and other uses. Four-lane to three-lane conversions are the most common road diet, but numerous types exist (e.g., three lanes to two lanes or five lanes to three lanes). FHWA identifies road diets as a proven safety countermeasure (FHWA 2008) and an “Every Day Counts” initiative (FHWA n.d.c).

Road diets are one approach to rebalancing a street to better meet the needs of all users. A conventional approach to evaluate the feasibility of a road diet is to evaluate the impact on vehicles, not people. Guidance at the national level provides the flexibility to apply engineering judgment to assess the project holistically, incorporating performance measures for all modes, community goals and compatibility with area context.

Case studies demonstrate that road diets reduce conflicts at intersections, reduce accidents and have minimal effects on traffic capacity and diversion on roadways traveled by fewer than 20,000 vehicles per day. Three-lane roadways can improve emergency response by allowing emergency vehicles to bypass congestion by using the two-way left-turn lane that is typically provided. They also create opportunities for pedestrian refuges at mid-block and intersection crossings, and they eliminate the common “multiple threat” hazards pedestrians experience crossing four-lane roads. Other benefits of three-lane roadways include easier egress from driveways (improved sight distance), smaller curb return radius by increasing the effective radius of the road, improvements for transit (by allowing curbside stops outside of travel lane) and buffering of street tree branches from closely passing trucks.

Road diets can improve the flow of traffic and reduce travel speeds, particularly when used in conjunction with roundabouts; however, converting four-lane roads to three lanes with a raised median and on-street parking may result in the traveled way’s inability to meet local fire districts’ minimum clear traveled way requirements.

According to the FHWA’s *Road Diet Informational Guide*, the common four- to three-lane road diet has proven safety benefits with “a 19 to 47 percent reduction in overall crashes” (FHWA 2014f). Adding two-way left-turn lanes reduces the number of potential conflict points, while slower operating speeds typical of this type of road diet reduce the severity of crashes that do occur. In addition to the reduction of speed, pedestrian safety benefits include potentially reduced crossing distances, space for refuge islands, and elimination of multiple threat crashes. Often, road diets also result in a dedicated space for standard or separated bike lanes.

For more detailed information, design guidance and case studies regarding road diets, designers can refer to these sources:

- *Road Diet Desk Reference* (FHWA 2015e);
- *Road Diet Informational Guide* (FHWA 2014f);
- *Evaluation of Lane Reduction “Road Diet” Measures on Crashes* (FHWA 2010c); and
- *Road Diet Handbook: Setting Trends for Livable Streets* (Rosales 2006).

4.3.6.2 Main Streets

Until the 1960s and 1970s, *main streets* were the principal roadways in many cities. They were corridors where people could park and walk to find all types of goods and services and often served as the center of local commercial, social and civic activities. Over time, many main street districts were replaced with larger scale, automobile-oriented shopping centers that were located closer to suburban areas and away from downtowns. Today, many of those same communities are attempting to revitalize their main street corridors to create places where residents and visitors can again park, walk, shop, eat and interact with other people. Bicycling also is becoming an important part of many revitalized main street corridors.

Although main streets vary from community to community, some typical characteristics can be observed. Main streets may be located in any context zone, but they are most commonly found in small towns and the suburban, urban and urban core areas of larger metropolitan areas. They are usually short, multimodal segments of longer arterial or collector streets and will often exist within a grid or interconnected system of local streets that serve the commercial center of town. These areas usually have short blocks, on-street parking, few driveways and buildings served by alleys.

Ideally, land uses on main streets will often consist of compact, mixed-use development, usually with a strong retail and entertainment emphasis on the ground floors of buildings and an equal mix of residential and/or commercial office or services on the upper floors. The buildings typically are low-scale and are oriented to the street with no setback. Parking lots or garages often are located behind or to the side of buildings. Public parking consists of on-street parking and may include strategically located parking lots or garages that support a visitor’s ability to park in one place and walk to multiple destinations.

The design of main streets will usually include roadsides that support active uses (e.g., street cafes, social interactions, strolling and window-shopping). By tradition and design, main streets are pedestrian friendly and may feature historic or contemporary examples of urban design, public spaces or public art. Many main streets will have no more than two travel lanes, will provide on-street parking and may contain bicycle lanes. Wider main streets may have additional vehicle lanes and center turn lanes, but the on-street parking and roadside features typically remain the same.

From a roadway design perspective, a successful main street will include design features that support a main street environment that focuses on local access, convenient parking, comfortable pedestrian and bicycle accessibility, low-speed traffic and good access to transit (where it exists). Tight corner radii will usually be used at intersections, and curb extensions may be used both at intersection corners and in mid-block crossing locations to shorten roadway crossing distances and increase pedestrian visibility. The physical and visual roadway and urban design elements that draw together both sides of the street should encourage and support frequent, safe crossings of the street. Achieving this typical set of goals for a main street environment will often require trade-offs in the design process, particularly when the main street also serves as a regional route and may be a state or federal-aid highway.

4.3.6.3 *Traveled Way Design Considerations for Main Streets*

In designing the traveled way of a main street project, there are three typical elements to consider: speed, width and parking. The pedestrian-oriented nature of main streets means the target speed should be kept low (25–30 mph) even when the roadways functional classification and role in the network might suggest higher speeds. Lower speeds create a safer environment for pedestrians, bicyclists and on-street parking maneuvers. Restricted sight distances also may exist in main street corridors, making lower design and operating speeds more appropriate.

Given that the width of the traveled way affects users' perceptions of the speed and volume of street traffic, wider streets often act as a barrier to comfortable pedestrian crossings. Wider streets may be required to implement angle on-street parking, which is sometimes used in main street settings to increase the number of overall parking spaces, but the number of travel lanes should normally not be increased beyond two or three lanes. The use of the traveled way and the number of lanes to be provided should be based on a design development process that considers current and future user needs, context, community objectives, the main street's role in the larger transportation network and the existence of alternative routes.

On-street parking is considered an important design element on main streets. It provides a source of short-term parking for adjacent retail and service uses, buffers pedestrians from traffic, creates friction that slows traffic and produces a higher level of street activity. This Guide provides design guidance for on-street parking in the section labeled "On-Street Parking Principles and Considerations."

Roadside design features in main street projects need an appropriate width to accommodate anticipated levels and types of all current and future activity. The clear pedestrian throughway should typically be wide enough, at a minimum, to allow two people to walk side-by-side. The frontage zone should allow for window-shopping, seating, displays and pedestrian activity at building entrances. The furnishings zone should be able to accommodate many functions, including street trees, planting strips, street furniture, utilities, bicycle racks, transit stops (if needed) and possibly even public art. Community goals may include having street cafes for restaurants located on the main street. If local regulations allow restaurants to have street cafes, then the roadside furnishings zone should allow for that.

The edge zone of the roadside will need to accommodate frequent car door openings from on-street parking as well as parking meters and signage. Roadside lighting typically provides both safety illumination of the traveled way and intersections and pedestrian-scaled lighting for the pedestrian walkways.

When a planned main street also serves as a state highway, especially in smaller towns where rural highways or principal arterials pass through the community's historical commercial district, achieving all the community's main street design objectives may be difficult. These roadways may be subject to state department of transportation (state DOT) policies and design standards. In these situations, it is best to work closely with the state DOT at the earliest stages of project planning and design.

Although the state agency may recognize the value the community places on their main street and be willing to allow for some flexibility in the design process, it may be difficult to achieve consensus on all the community's desired main street design elements and criteria. The key to successful planning and implementation of main streets that effectively serve all users and meet community objectives is working collaboratively with the state DOT and all other stakeholders to collectively define a vision, goals and objectives from which a guiding project purpose and need are developed. The objective of this collaboration is for the parties to develop an early consensus on the design concept plan and any design features that may require special approvals.

4.3.6.4 Shared and Slow Streets

Shared streets (sometimes called *flush streets* or *woonerfs*) prioritize pedestrian and bicycle movement by slowing vehicular speeds and communicating clearly through design features that motorists must yield to all other users. Shared streets use various design elements to blur the boundary between pedestrian and motorized vehicle space. The right-of-way design should create conditions in which pedestrians and bicyclists can walk or ride on the street and cross at any location, as opposed to at designated locations. This encourages cautious behavior on the part of all users, which in turn reinforces slower speeds and comfortable walking and bicycling conditions.

By slowing the travel speed of all modes, shared streets encourage social interaction and lingering. They support a variety of adjacent land uses including commercial and retail, entertainment venues, restaurants, offices and residences, while still accommodating commercial loading and transit operations. Shared streets have also been shown to increase economic vitality and vibrancy.

Little design guidance for shared streets exists in the United States, but European countries have successfully applied the concept for decades. Additional research is needed to identify design elements and criteria for this unique type of shared-space design for motorized and non-motorized users. Until that research occurs, a designer exploring the use of a shared street should consider the following:

- The design, operations, and maintenance of shared streets should always encourage lower vehicle speeds, reducing the likelihood and severity of crashes.
- Shared streets are considered self-enforcing roads, designed and operated primarily for pedestrian traffic. Designs for shared streets should lead to slow vehicular speeds. The maximum design speed should not exceed 20 mph, and the preferred design speed is between 10 mph and 15 mph.
- Design details should communicate clearly that the shared street is a multimodal environment where pedestrians are given priority and motorists are guests on the street who must proceed slowly and cautiously. The lack of predictability of all users heightens awareness, thereby creating lower vehicle speeds and reducing conflicts.
- The shared street should support adjacent land uses and support economic and livability goals.
- Typically, shared streets do not use vertical curbs; that is, the entire street surface is flush, with minimal separation between sidewalks and the traveled way. Although sloping curbs discourage motorized vehicle encroachment, they have limited ability to prevent a vehicle from driving onto the sidewalk. Designers can choose from among several techniques to control drainage and help delineate the roadway edge. The *Urban Street Design Guide* (NACTO 2013) includes information on such techniques, with sections that cover both residential and commercial shared streets.
- Shared streets should carry no more than 100 vehicles during the peak hour for pedestrians to feel comfortable sharing the road with motorists (NCUTLO 2000). If volumes exceed this threshold, designers can consider restricting access for specific vehicle types to reduce volumes. If vehicular volumes are too high, pedestrians will avoid the middle part of the street. Depending on the role of the shared street in the transportation network, personal vehicles may be directed to alternative routes while taxis and freight and transit vehicles are allowed. Emergency access should be maintained on shared streets.
- At intersections, designers should consider traditional marked crosswalks and detectable warning surfaces in order to alert pedestrians of potential vehicular conflicts. Gateway features such as signs, raised crossings, raised intersections or curb extensions can be used to alert drivers entering the shared street of the intended use of the space and the appropriate speed.

- Shared street design should use creative means to delineate space for pedestrians with disabilities. This can be done by providing a frontage zone along buildings where a traditional sidewalk is located. The frontage zone can be delineated using a distinct paving treatment, drainage infrastructure, trees, street furniture, art, or parking. Paving textures in the frontage zone should be smooth and vibration free, with a minimum of 5 ft. of clear space.

Some shared street concepts offer a great deal of flexibility in how the space is designed and used. Without vertical curbs, the street can be closed to offer space for events, or to more comfortably provide outdoor seating space for cafes and restaurants. Designers can choose from among several options for drainage design and the delineation of space. Through the thoughtful use of urban design principles, these streets can enhance the sense of place and emphasize the pedestrian and bicycle priority of the street. A multipurpose shared street allows for different uses of the space on different days of the week, times of day or seasons, extending the public space at times of celebration, special events or festivals. Sidewalks, parking and vehicle travel lanes can be made available at various times. Movable planters, metal barricades or signs can regulate the use of the space on a temporary or regularly scheduled basis.

Slow streets are designed to enhance safety and improve pedestrian and bicycle comfort by achieving low motorist speeds and minimizing speed differentials between motorists and bicyclists to prioritize bicycle travel. The lower motorist speeds also promote increased yielding to pedestrians crossing the street. Slow streets also may be called bicycle boulevards, quiet-ways or neighborhood greenways. Typically, they are designed for a maximum speed of 20 mph to 25 mph, with the majority of motorists going slower. Slow streets may require the use of traffic-calming measures (e.g., curb extensions, speed tables, gateway treatments, neighborhood traffic circles, textured pavement and chicanes).

Design speeds for slow streets typically are established at or below 20 mph. This design speed reduces the speed differential between roadway users, thus providing a higher level of comfort and safety. Good candidates for slow streets include neighborhood residential streets, school walking routes, bicycle routes and shopping streets with high levels of pedestrian activity. Slow streets also are appropriate on streets running adjacent to (or through) parks and public plazas. Lower-speed streets with comfortable pedestrian crossings enhance adjacent public spaces, whereas higher-speed streets and streets with higher vehicle volumes and difficult crossings can detract from them.

Slow streets often have a narrowed traveled way (less than 18 ft. in total width) that, in some cases, requires oncoming motorized vehicle traffic to yield before proceeding. Alleys demonstrate this strategy for slow street design. Some slow streets will include bollards, planters and other vertical elements in close proximity to the traveled way, encouraging caution as drivers move along the street. Used in conjunction with other features that reduce speed, the removal of traffic controls at intersections is another strategy to produce cautious behavior in motorists (and therefore slower speeds). Various other traffic-calming measures can be used to slow the speeds of motorized vehicles, provide comfortable places for vulnerable road users and encourage motorist yielding.

Slow streets are inherently beneficial to pedestrians of all abilities because they produce slower and more cautious behavior on the part of motorists. Design elements of slow streets must meet current accessibility standards. For example, all surfaces within pedestrian areas must be designed and maintained to be stable, firm and slip resistant.

Bicycle boulevards (or bicycle priority streets) are a form of slow street. They have lower motorized vehicle speeds that are designed to allow bicyclists to travel comfortably in a low-stress environment. Bicycle boulevards typically give priority to bicycle use and discourage through traffic by motorized vehicles. They are designed to minimize the number of stops that a bicyclist must

make along the route. Designers have a great deal of flexibility when designing bicycle boulevards. They are easier to implement in areas with a grid street network because drivers have the option to choose an alternate route. Bicycle boulevards typically are designated using special signs or pavement markings. More information on bicycle boulevard design can be found in the AASHTO Bicycle Guide (AASHTO 2014b) and the NACTO *Urban Bikeway Design Guide* (NACTO 2014).

4.3.7 One-Way Streets

One-way streets simplify crossings for pedestrians, who must look for traffic in only one direction. Although studies have shown that conversion of two-way streets to one-way streets generally reduces pedestrian crashes, one-way streets tend to have higher speeds, which creates greater chances for fatalities and increased injury severity among the crashes that still occur. If a street is designed as a one-way facility, it should be evaluated to see if additional design elements should be added to reduce pedestrian and bicycle crash potential, especially if the traveled way or lanes are overly wide.

Other considerations for one-way streets include the following:

- As a system, one-way streets can increase travel distances for motorists and create some confusion, particularly for non-local residents.
- One-way streets operate best in “street pairs” that are separated by distances ranging from one block to no more than one-quarter mile. Conversion costs can be quite high to build cross-overs where the one-way streets convert back to two-way streets, and to rebuild traffic signals and revise striping, signing and parking meters.
- One-way streets work best in downtown areas or other very heavily congested areas. One-way streets can offer improved signal timing and accommodate odd-spaced signals, but signal timing for arterials that cross a one-way street pair is difficult.

4.3.7.1 One-Way/Two-Way Street Conversions

Converting a one-way street to a two-way street is an increasingly popular way to manage traffic patterns, simplify access and change the character of a corridor or neighborhood from a “pass-through” facility to a “destination” for motorists. Converting a one-way street to a two-way street also can help reduce motorized vehicle speeds and VMT (because there is less need to circumnavigate multiple streets to reach destinations in dense mixture of land uses) and can provide improved conditions and access for bicyclists and pedestrians.

In terms of pedestrian safety, one-way and two-way streets both have benefits, so the decision to convert a two-way street to one-way (or vice versa) is context sensitive. Studies have shown that converting two-way streets to one-way streets generally results in fewer crashes involving pedestrians because there are fewer turning movements. On the other hand, one-way streets tend to encourage higher motorized vehicle speeds, and intersections involving one-way streets may be more confusing for some roadway users, especially non-local residents and child pedestrians. In addition, left-turning drivers of motorized vehicles may be less cautious when turning from one-way streets and therefore less likely to see crossing pedestrians due to poorer sight lines. In addition, many one-way streets are multilane, which creates a multiple threat condition for pedestrians crossing the road. Converting a multilane one-way street to a two-lane two-way eliminates this safety issue. Two-way streets may reduce vehicle speeds due to increased turning movements and to increased perceived friction along the roadway.

If a two-way street will be converted to one-way, the street should be evaluated to see if additional changes should be made. Potential changes can include lane diets, road diets, curb

extensions, turning radius reductions and use of signal timing that discourages high vehicle speeds. In addition, traffic circulation in the surrounding area must be carefully considered before converting streets to one-way.

4.3.8 Bridges

Bridge crossings are significant investments and therefore often occur infrequently. Thus, it is critical that they accommodate pedestrians and bicyclists (FHWA 2016a). A bridge without walking and bicycling access can result in a lengthy detour that makes the entire trip impractical for pedestrians or bicyclists.

Safe pedestrian access often can be included at the same time as bicycle accommodations and should be provided on bridges whenever possible, regardless of funding source. Bridges also should accommodate the bicyclists and pedestrians who may travel under them so that they do not create a barrier. Providing pedestrian and bicycle accommodation during initial construction generally costs less than retrofitting.

Federal policy often requires safe accommodation of pedestrians and bicyclists, and design guidance provides adequate flexibility on how to accommodate these users.

Federal law states: “In any case where a highway bridge deck being replaced or rehabilitated with [f]ederal financial participation is located on a highway on which bicycles are permitted to operate at each end of such bridge, and the Secretary determines that the safe accommodation of bicycles can be provided at reasonable cost as part of such replacement or rehabilitation, then such bridge shall be so replaced or rehabilitated as to provide such safe accommodations” (23 USC §217(e)).

Design guidelines for the accommodation of pedestrians and bicyclists on bridges are as follows.

- Bridge designs should provide adequate width for current and anticipated pedestrian and bicycle use. Sufficient clear width and usable width should be provided. Clear width is a traveled way clear of obstructions such as railings, light poles, or signs (TRB 2016b). The usable width recognizes that pedestrians and bicyclists will not travel at the very edge of a traveled way or immediately against a railing, but need at least 1.5 ft. of shy distance from vertical objects (TRB 2016b).
- Both sides of the bridge should accommodate travel for pedestrians and bicyclists. Where bidirectional facilities can be provided, they may reduce conflicts if they limit the number of roadway crossings. Similarly, facilities should be considered for current and anticipated pedestrians and bicyclists to access the bridge and travel under the bridge. Designers should consider whether to combine pedestrians and bicyclists on a shared-use path or to separate them.
- The desirable clear width for a sidewalk on a bridge is 8 ft. (AASHTO 2004a).
- The minimum width for one-way bicycle travel is 4 ft. (AASHTO 2014b).
- Well-designed bridge railings can contribute to a safer and more positive experience on bridges for people who walk or bicycle. Railing designs should consider a 1.5 ft. shy distance when determining usable width, and establish a height that keeps pedestrians and bicyclists safe. Given that bicyclists have a higher center of gravity, railings should be a minimum of 42 in. high. Where bicyclists’ handlebars or pedals may come into contact with the railing, smooth and wide rub-rails should be installed; furthermore, on bridges that accommodate both vehicular and pedestrian/bicycle travel, only crash-tested railings should be installed (AASHTO 2014b).
- Connections from bicycle and pedestrian facilities on a bridge to related roadway features such as shared-use paths, sidewalks, or other infrastructure are a key component of connected

networks. Any connection for use by pedestrians must be accessible to people with disabilities. The design should consider the desired route of pedestrians and bicyclists. A common practice is to install switchbacks, which may be the only option in a confined space; however, designs without switchbacks often create a more direct route for the majority of users. Grades must meet accessibility standards and ramps may be required. Where switchbacks are required, the ramp turns should provide generous width to better accommodate turns by bicyclists. Where bicyclists are permitted to use the connection, the ideal design should not require bicyclists to dismount (AASHTO 2014b).

- Stairs may provide a more direct connection for pedestrians and bicyclists, but the accessible route provided for persons with disabilities may not be significantly longer. The stairs can be constructed to accommodate bicycles by including a bike channel (a flat ramp parallel to the stairs on which to roll the bicycle). Handrail designs must meet current accessibility standards. Specifically, handrails provided on stairs with a bike channel need to project out from the wall with at least the minimum clearance required by ADA accessibility guidelines, and the handrail must be aligned above the stair nosing where people are walking. Pedestrians must be able to easily reach the railing, and the bike channel must not present a tripping hazard for pedestrians with visual disabilities.
- Pedestrians and bicyclists may find it difficult to locate bridge access points from the connecting street grid. In some cases, access points for people on foot, in wheelchairs or on bicycles are different and more difficult to locate than vehicle access points. Wayfinding signs and markings should direct users of all travel modes to bridge access points.
- Including facilities for pedestrians and bicyclists on bridges increases access, but the bridge design itself may reduce future connectivity. Waterways, railroads, and highways may be desirable corridors for shared-use paths. Whether or not a current plan exists to build a path along one of these corridors, bridge design should consider future accommodations for pedestrians and bicyclists under the bridge.

4.3.9 Railroad-Highway Grade Crossings

Many types of railways exist in urban and suburban areas. Although the heavy rail that has traditionally served freight and passenger needs for more than 100 years is most prevalent, new types of passenger rail systems are being increasingly employed in urban areas. These new systems include LRT, modern streetcars and trolleys.

In urban areas where pedestrian and bicycle volumes are higher, many—but not all—crossings of higher-speed and higher-volume train tracks with major roadways and streets are grade separated. Newer types of passenger rail systems often operate within rights-of-way that are adjacent to the roadway. The traditional crossings of heavy rail track and roadways present one type of challenge to the designer, whereas the newer, integrated light rail systems offer quite a different challenge. In urban and suburban areas, pedestrians, bicycles and transit vehicles often travel in great numbers and proximity to both heavy and light rail lines, and they must be considered in the design of railroad-highway (railroad-roadway) crossings just as motorized vehicles are.

Railroad-roadway grade crossings are designed and controlled to accommodate the vehicles and other users that travel across them. The vast majority of the vehicles consist of automobiles, buses and all types of trucks. Generally speaking, the improvements made to a crossing with these users in mind will be adequate for special users such as trucks carrying hazardous materials, long-length trucks, school buses and motorcycles. Designing these crossings for safe and convenient use by bicycles and pedestrians presents a different challenge. These users have unique characteristics and special needs that should be carefully considered in the design of railroad-roadway crossings.

The type, size and design of pedestrian and bicycle facilities along a street or roadway should be carried across the rail tracks such that there is no reduction of service accommodation to those users. In addition, the warning and protection systems used in passive and active crossing systems for vehicles should be designed and operated to serve the non-vehicle users as well.

4.3.9.1 Buses

Because buses carry many passengers and have performance characteristics similar to large trucks, these vehicles need special consideration. Many of the measures suggested for trucks with hazardous material apply to buses. Railroad-roadway grade crossings should be taken into consideration when planning school bus and transit routes, not least because school bus routes may contribute to added pedestrian or bicycle travel by children, and transit routes may attract similar pedestrian or bicycle travel by commuters of all ages and abilities. Potentially hazardous crossings (e.g., crossings with limited sight distance or horizontal or vertical alignment issues) should be avoided if possible. Crossings along school bus and transit routes should be evaluated by the appropriate roadway and railroad personnel to identify potential dangers and the need for improvements.

4.3.9.2 Motorcycles and Bicycles

Although motorcycles and bicycles typically travel at different speeds, these two-wheeled vehicles can experience similar problems at railroad-roadway crossings. Depending on the angle and type of crossing, a bicyclist may lose control if the wheel of the bicycle becomes trapped in a flange way. Particular attention should be given where streetcar tracks bend or turn, where light rail tracks cross a street, or where bicycle lanes or bicycle turning movements cross tracks. Bicycling adjacent to tracks also poses dangers, which become particularly pronounced when a bicyclist must be prepared to swerve to avoid unforeseen obstacles such as opening vehicle doors. Bicycle-friendly track crossings are applicable wherever

- Streetcar or light rail tracks turn across a bikeway (including any bike lane, bike boulevard or cycle track),
- A bikeway turns across tracks, and
- An intersection accommodates bicycle turns (especially where two bike lanes intersect).

Bicycle-friendly trackway design is applicable to all mixed-traffic streetcar/trolley and LRT running ways.

The *Transit Street Design Guide* (NACTO 2016) provides several design recommendations for keeping bicyclists safe at rail crossings, including:

- Where bicycle paths of travel cross a street-surface rail track, bicyclists must be directed to cross tracks at a high angle. While 90-degree crossings are preferred, 60 degrees is the minimum design angle for bikeways to cross in-street rails. Bicyclists must be able to cross tracks fully upright and not leaning, with perpendicular or high-angle approaches established in advance of tracks to allow riders to right themselves.
- A *bike sneak* [a design concept developed to address rail turns across bikeways] is a short section of bicycle lane, protected bicycle lane, or raised cycle track that is bent out (bent toward the sidewalk) to direct bicyclists at a safe angle across turning tracks. Provide bicycle lane markings to direct bicyclists to the right, establishing sufficient space for a safe crossing of rails. Provide intersection markings, at or near a 90-degree angle to the curving track that return bicyclists to the bicycle lane on the opposite side of the intersection without entering the motor vehicle lane. The bike sneak can be marked, raised, channelized, or otherwise protected using a variety of means of separation, depending on the volume of bicyclists and the role of the street in the bicycle network.
- Crossing tracks at an angle less than 45 degrees should be discouraged, both on streets with and without a bicycle facility.
- Warning signage or markings should be used ahead of an intersection or other rail crossing where the natural travel path of a bicyclist, generally parallel to the lane line or curb-line, would cross the rail at a low angle.

- Two-stage turn queue boxes direct bicyclists to cross rails at a safe angle when turning left across tracks, or turning right across tracks from a left-side bikeway. (Refer to the *Urban Bikeway Design Guide* [NACTO 2014] for guidance on two-stage turn queue box design).
- Bicycle lanes should include a buffer at least 3 ft. wide to account for these instances, and prohibitions of dangerous misuse of the bike lane, such as double-parking, must be strictly enforced. Where possible, physically separating bicycle lanes from streetcar lanes is preferred. In addition to cycle tracks, placing rails on raised beds or transitway design treatments, such as rails in raised beds, or vertical separation, prevent bicycles from entering tracks. Vertical separation may be especially desirable in tight spaces. If curbs are greater than 2 in., roll curbs or mountable curbs should be considered.

4.3.9.3 Pedestrians

The safety of pedestrians crossing railroads is the most difficult to control because of the relative ease with which pedestrians can go under or around lowered gates. Pedestrians typically seek the shortest path, and they may not always cross the tracks at a designated roadway or pedestrian crossing. Given the variety of factors that may contribute to pedestrian hazards, detailed studies often are necessary to determine the most effective measures to provide for pedestrian access and safety at specific locations. A variety of preventive design measures can be employed as discussed in this section. ADA guidelines for accessible design also provide many geometric features pertaining to pedestrian facilities that address minimum widths and clearances, accessible routes and pedestrian pathways, curb ramps and protruding objects (U.S. Access Board 2002, U.S. Access Board 2005, U.S. Access Board 2011).

Although collisions between light rail vehicles (LRV) and pedestrians occur less often than collisions between LRVs and motorized vehicles, they are more severe. Furthermore, pedestrians often are not completely alert to their surroundings at all times, and LRVs operating in a street environment are nearly silent. For these reasons, appropriate pedestrian crossing-control systems are critical for LRT safety. The following pedestrian crossing treatments may be warranted at rail-pedestrian crossings:

- **Flashing light signal.** At non-gated pedestrian-only crossings of semi-exclusive LRT rights-of-way, a flashing light signal assembly with an audible component serves as the primary warning device where LRT operates two ways on one track or on a double track. When the red lenses of the light signal are flashing alternately and the audible device of the signal assembly is active, the pedestrian is required to remain clear of the tracks (Uniform Vehicle Code, Section 11-513, NCUTLO 2000).

At gated motorized-vehicle LRT crossings without pedestrian gates, *TCRP Report 17: Integration of Light Rail Transit into City Streets* recommends that the flashing light signal assembly be used in the two quadrants without vehicle automatic gates (Korve et al. 1996). According to this recommendation, these signal devices should be installed adjacent to the pedestrian crossing facing out from the tracks. The signal assembly includes a standard crossbuck sign and, where there is more than one track, an auxiliary inverted T-shaped sign indicating the number of tracks.

- **“Second Train Coming” sign.** An LRV-activated, internally illuminated matrix sign displaying the pedestrian crossing configuration with one or more LRVs passing may be used to alert pedestrians to the direction from which one or multiple LRVs are approaching the crossing, especially at locations where pedestrian traffic is heavy (such as LRT stations). Alternatively, an LRV-activated, internally illuminated flashing sign with the legend, “SECOND TRAIN—LOOK LEFT/RIGHT,” may be used to alert the pedestrian that a second LRV is approaching the crossing from a direction that the pedestrian might not be expecting. This sign warns pedestrians that, although one LRV has passed through the crossing, a second LRV is approaching, and that other warning devices (such as a flashing light signal assembly and bell) will remain active until the second LRV has cleared the crossing.

TCRP Report 17 recommends that the “Second Train Coming” sign be placed on the far side of the crossing (and on the near side as well if necessary for pedestrian visibility), especially

when the crossing is located near an LRT station, track junction, and/or multiple track alignment involving more than two tracks (Korve et al. 1996). When this sign is activated, only one direction—left or right—is illuminated at any time. Furthermore, only one arrow—to the left of “LOOK” or the right of “RIGHT”—is illuminated at any time (the one that points in the direction of the second approaching LRV). Therefore, if two LRVs are very closely spaced so that they will pass through the pedestrian crossing almost simultaneously, *TCRP Report 17* recommends that this sign not be activated. In this situation, pedestrians will have no opportunity to cross between the successive LRVs, and pedestrians will need to look in both directions.

- **Dynamic envelope markings.** *TCRP Report 17* recommends that the LRV’s dynamic envelope be delineated at pedestrian crossings in semi-exclusive rights-of-way and along entire semi-exclusive and nonexclusive corridors. According to this recommendation, contrasting pavement texture should be used to identify an LRV’s dynamic envelope through a pedestrian crossing. A solid 4-in.-wide line may be used as an alternative. Tactile warning strips approved by the ADA can be considered a contrasting pavement texture, and their requirement may supersede the use of painted striping or other contrasting pavement texture. *TCRP Report 17* recommends that in an LRT/pedestrian mall, the dynamic envelope be delineated in its entirety (Korve et al. 1996).

In addition to pedestrian signals (including flashing light signals), warning signs, and dynamic envelope markings, several pedestrian barrier systems have proven effective in reducing collisions between LRVs and pedestrians. These barriers, and the transit systems or railroads where they have been successfully installed, include:

- **Curbside pedestrian barriers.** Between intersections in shared rights-of-way, *TCRP Report 17* recommends that curbside barriers (landscaping, bedstead barriers, fences and/or bollards and chains) be provided alongside-aligned LRT operations where LRVs operate two ways on a one-way street (contra-flow operations). They may also be provided for one-way side-aligned LRT operations for normal flow alignments (Korve et al. 1996).
- **Pedestrian automatic gates.** Pedestrian automatic gates are the same as standard automatic crossing gates except that the gate arms are shorter. When they are activated by an approaching LRV, the automatic gates are used to physically prevent pedestrians from crossing the LRT tracks. *TCRP Report 17* recommends that this type of gate be used in areas where pedestrian risk of a collision with an LRV is medium to high (for example, whenever LRV stopping sight distance is inadequate). The preferred method is to provide pedestrian automatic gates in all four quadrants. *TCRP Report 17* provides additional detail on the design and operation of this method (Korve et al. 1996).
- **Swing gates.** Sometimes used in conjunction with flashing lights and bells, swing gates alert pedestrians to the LRT tracks that are to be crossed and force them to pause, thus deterring them from running freely across the tracks without unduly restricting their exit from the LRT right-of-way. The swing gate requires pedestrians to pull the gate to enter the crossing and push the gate to exit the protected track area; therefore, a pedestrian cannot physically cross the track area without pulling and opening the gate. *TCRP Report 17* recommends that the gates be designed to return to the closed position after the pedestrian has passed (Korve et al. 1996).

Swing gates may be used at pedestrian-only crossings, on sidewalks and near stations (especially if the station is a transfer point with moderate pedestrian volumes) where pedestrian risk of a collision with an LRV is medium to high (e.g., where conditions include moderate stopping sight distance, moderate pedestrian volume, and so forth). These gates may be used at pedestrian crossings of either single-track (one- or two-way LRT operations) or double-track alignments.

TCRP Report 17 recommends that swing gates be supplemented with proper signing mounted on or near the gates. Such signing can include the “LIGHT RAIL TRANSIT CROSSING/LOOK BOTH WAYS” sign (where LRVs operate two ways), LRV-activated, internally illuminated

warning signs, and/or flashing light signal assemblies. Where LRVs operate using a single-track, two-way alignment, *TCRP Report 17* recommends that an LRV-activated, internally illuminated matrix sign or active, internally illuminated sign with the legend, “TRAIN—LOOK LEFT/RIGHT” be installed to supplement swing gates (Korve et al. 1996).

- **Bedstead barriers.** The bedstead concept may be used in tight urban spaces that lack a fenced-in right-of-way, such as a pedestrian grade crossing at a street intersection. The barricades are placed in an offset (maze-like) manner that requires pedestrians moving across the LRT tracks to navigate the passageway through the barriers. *TCRP Report 17* recommends that bedstead barriers be designed and installed to turn pedestrians toward the approaching LRV before they cross each track, forcing them to look in the direction of any oncoming LRV. According to this recommendation, the barriers should also be used to delineate the pedestrian queuing area on both sides of the track area (Korve et al. 1996). Bollards and chains accomplish the same effect as bedstead barriers. Bedstead barriers may be used for crossings where pedestrians are likely to run unimpeded across the tracks, such as stations or transfer points, particularly where pedestrian risk of a collision with an LRV is low to medium (e.g., where stopping sight distance is excellent to moderate, where double tracking is used and where pedestrian volume is low). *TCRP Report 17* recommends that the barriers be used in conjunction with flashing lights, pedestrian signals and appropriate signing. Bedstead barriers also may be used in conjunction with automatic gates in high-risk areas (Korve et al. 1996).

TCRP Report 17 recommends that bedstead barriers not be used when LRVs operate in both directions on a single track because pedestrians may look the wrong way in some instances (Korve et al. 1996). Pedestrians also may look in the wrong direction during LRV reverse-running situations; however, reverse running is performed at lower speeds, so this should not be a deterrent to this channeling approach.

- **Z-crossing channelization.** The Z-crossing controls movements of pedestrians approaching LRT tracks. Its design and installation turn pedestrians toward the approaching LRV before they cross each track, forcing them to look in the direction of oncoming LRVs. Z-crossing channelization may be used at crossings where pedestrians are likely to run unimpeded across the tracks, such as isolated, mid-block, pedestrian-only crossings, particularly where pedestrian risk of a collision with an LRV is low to medium (e.g., locations with excellent stopping sight distance, double tracking, low pedestrian volume and so forth.).

Z-crossings used with pedestrian signals create a safer environment for pedestrians than Z-crossings used alone. This channelization approach also may be used in conjunction with automatic gates in high-risk areas. *TCRP Report 17* recommends that the Z-crossings not be used when LRVs operate in both directions on a single track because some pedestrians may look the wrong way (Korve et al. 1996). Pedestrians also may look the wrong way during LRV reverse-running situations; however, reverse running is performed at lower speeds, so the risk to pedestrians is lower and should not be a deterrent to a Z-crossing channeling approach.

- **Combined pedestrian treatments.** The pedestrian crossing/barrier systems described in this section may be used in combination, depending on the risk of a pedestrian collision with an LRV at the crossing. Pedestrian safety and queuing areas should always be provided and clearly marked.

The key design references for design of pedestrian, bicycle, transit and vehicle crossings of rail facilities are:

- *Guide for Geometric Design of Transit Facilities on Highways and Streets* (AASHTO 2014a);
- *TCRP Report 17: Integration of Light Rail Transit into City Streets* (Korve et al. 1996);
- *Transit Street Design Guide* (NACTO 2016);
- *TCRP Report 183: A Guidebook on Transit-Supportive Roadway Strategies* (Ryus et al. 2016);
- *TCRP Report 175: Guidebook on Pedestrian Crossings of Public Transit Rail Services* (Fitzpatrick et al. 2015b);

- *TCRP Report 117: Design, Operation, and Safety of At-Grade Crossings of Exclusive Busways* (Eccles and Levinson 2007); and
- *TCRP Report 112/NCHRP Report 562: Improving Pedestrian Safety at Unsignalized Crossings* (Fitzpatrick et al. 2006).

4.3.10 Fire and EMS Considerations

Roadway designs must consider the needs of emergency responders driving fire trucks and emergency medical service (EMS) vehicles. Emergency responders seek to minimize response times to save lives; in some situations, seconds can make the difference between life and death.

Many design treatments that can make roads and streets safer for pedestrians and bicycles can reduce the traveled way that emergency responders rely on, and some may reduce the operating speeds of motorized vehicles, including emergency response vehicles. However, pedestrian and bicycle deaths and injuries significantly decrease as motorized vehicle speeds decrease. Where vehicle speeds are a concern, applying speed management designs will improve pedestrian and bicycle safety and access, reduce the frequency and severity of vehicle crashes, and add parking lanes. Speed management designs also may provide opportunities to introduce green infrastructure elements to reduce stormwater runoff.

Urban roadways are the primary routes for emergency response vehicles, including police cars, fire trucks and ambulances. Common roadway designs that encourage speed and capacity can lead to fatality- and injury-producing crashes involving emergency vehicles and other motorists, bicyclists or pedestrians. Although the emergency responder bears the primary responsibility for both response time and reasonable access to incidents within the community, a balance among the competing interests of access, speed, capacity and safety must be established for the appropriate design of context-sensitive roadways. Stakeholders can work together to find emergency response strategies that create safe and comfortable places for the non-motorist.

Emergency vehicle access and operations always should be considered in roadway design. Local operational conditions will vary from community to community, and emergency response strategies are specific to the locale. Consequently, a designer should collaborate with emergency responders to learn their specific needs, response strategies and tactics used on similar streets. Although all emergency responders are concerned with the speed with which they can respond to a call, firefighting equipment generally involves the largest vehicles to be considered. Obtaining answers to the following questions will help designers understand and clarify issues when working with fire departments in the design process:

- What types of fire apparatus are used in responding to various emergencies that might occur on or adjacent to the roadway?
- Does the vehicle type change depending on the location of the emergency (e.g., a home on a suburban residential street versus a high-rise building in an urban core)?
- In urban areas with tall buildings, how does the department deploy its ladders? How much width is needed between the vehicle and building? How much clear space is needed adjacent to the building? Are gaps in sidewalk furnishings required to access buildings? Do the emergency responders need to fully extend their vehicle's stabilizers?
- What characteristics of the apparatus affect roadway design (e.g., what specifications are needed to accommodate the wheel turning path, the overhang turning path and the apparatus width)?
- In a block of attached multistory buildings, does the number of stories cause a difference in firefighting tactics that would affect the design of the adjacent street?

Fire codes may provide additional guidance on emergency access requirements such as minimum traveled way clear widths and minimum space to deploy certain types of equipment, such as ladders, to reach high buildings. The following approaches should be considered in designing traveled ways to accommodate emergency vehicles:

- In urban areas with tall buildings, consider placing no-parking zones or staging areas at mid-block to accommodate large ladder trucks. The length and frequency of these zones should be determined with the emergency responder but should be no longer than 50 ft. in order to minimize the loss of on-street parking.
- For the design of curb return radii, use emergency vehicles as a design vehicle only if the vehicle would use the roadway frequently (e.g., as a primary travel route from the fire station to locations in its service area). Otherwise, emergency vehicles are generally able to encroach into opposing travel lanes. Consider using demonstration projects in the field to determine or confirm the optimal geometry for firefighting vehicles.
- On streets with medians or other access management features, emergency response time may be reduced by implementing mountable median curbs to allow emergency vehicles to cross.
- On roadways that have one lane in each direction and medians, consider using bicycle lanes that are at least 6 ft. wide. With bicycle lanes in place, motorists have the opportunity to safely pull into the bike lane if necessary to allow emergency vehicles to pass.
- In high-rise building environments, roadway design may be constrained by the required distance between the building face and the centerline of ladder trucks. In many cases, the required distance is 35 ft.; this dimension varies, however, and it should be examined with fire officials.

Firefighters are trained in many techniques that address context-sensitive streets, mainly because narrow, low-speed, pedestrian-oriented streets exist in many towns and cities. Many fire departments have experience with historic networks of narrow streets. Their experience can provide a helpful basis for problem solving when new or updated road design projects take place within existing networks of relatively narrow streets. The designer should be particularly sensitive to the local fire official's experience and the operational needs on urban roadways.

4.3.11 Roadway Pavement Markings and Markers

In the design of facilities serving bicycle traffic, care should be taken to specify pavement striping that is durable yet skid resistant. Raised pavement markings and markers can deflect a bicycle wheel, causing a bicyclist to lose control.

All longitudinal and transverse pavement markings accessible to bicycles within the traveled way should be capable of maintaining an appropriate skid resistance under rainy or wet conditions to maximize safety for bicyclists. Normally, thermoplastic markings can meet these requirements. Skid resistance is optimized when the composition of the pavement marking has been modified with crushed glass to increase the coefficient of friction and the maximum thickness of the marking is no larger than 100 mils (2.5 mm).

Raised reflective markers and non-reflective ceramic pavement markers both can present a vertical obstruction to bicyclists. When reflective markers are necessary as a fog line or placed adjacent to the edge line, they should have a beveled front edge and be placed to the left of the line, outside the shoulder area. Where raised pavement markers cross a bike lane or extensions thereof through intersections, a 4-ft. gap should be provided as a clear zone for bicyclists. At gore areas and other locations with channelizing lines, if raised reflective markers are used to supplement the striping, extra lane width should be provided in the areas where bicycles travel to provide bicyclists with more latitude to avoid the markers. If retroreflective pavement markers are needed for motorists, they should be installed on the motorists' side of any bicycle lane stripe.



CHAPTER 5

Roadside Design Guidelines

5.1 General Considerations

In urban, suburban and rural town contexts, levels of non-motorized user activity typically warrant some provision of facilities for these users. Whereas Chapter 4 of this Guide focuses on criteria for design of the traveled way itself, this chapter provides guidance for the accommodation of pedestrians, bicyclists and transit users in the roadside area adjacent to the traveled way. It also addresses how the design of the roadside varies with changes in context

As noted in Chapter 4, balancing and blending modal accommodation in the geometric design process often involves technical analysis supported by a qualitative, even subjective, process involving policy choices, engineering judgment and the use of flexible and unique design approaches. These guidelines identify the ranges of flexibility that are available in current national design practice and guidelines for how to apply that flexibility. Greater awareness of the flexibility and versatility available in national guidance will help designers overcome many challenges related to both new and retrofit project designs.

5.1.1 Roadside Users, Uses and Activities in Low- and Intermediate-Speed Environments

5.1.1.1 Roadside Users

Roadside users normally include pedestrians, can include bicyclists, and sometimes include unique users such as skateboarders and rollerbladers. ADA also requires that roadside projects in the public right-of-way must accommodate users with disabilities, including persons with vision and hearing impairments and persons in wheelchairs or motorized scooters (U.S. Access Board 2011).

Pedestrians are the most vulnerable type of roadway user. Pedestrians are at the greatest risk of injury or death in a collision with someone traveling by any other mode. Bicyclists generally travel at slower speeds than motorized vehicles and are inherently more vulnerable in the event of a crash with a car, truck, or transit vehicle. Crash risks also exist between bicyclists and pedestrians when these users share the same space, with pedestrians often at a disadvantage in those crash situations because of the speed differential. The roadside is frequently crossed by vehicular access driveways in urban and suburban contexts, which creates additional conflict risks for all non-motorized users.

Roadways and streets should be designed to operate at speeds that create comfortable environments for pedestrians and bicyclists as well as reasonable accommodation for motorized vehicles. Roadway traveled way designs in contexts with pedestrian and/or bicycle activity should attempt to limit excessive speeding, and design speeds should be appropriate for the road classification and context of surrounding land uses. On existing roads and streets with operating speeds considered

excessive or inappropriate for roadside pedestrians and bicyclists, traffic calming measures should be considered to reduce speeds to improve safety and comfort for all users.

Pedestrians and bicyclists are particularly vulnerable in the event of a crash. Speed is of fundamental importance: the severity of a pedestrian injury in the event of a crash is directly related to the speed of the vehicle at the point of impact. For example, a pedestrian who is hit by a motorized vehicle traveling at 20 mph has an approximate 95 percent chance of survival, whereas a pedestrian hit by a motorized vehicle traveling at 40 mph has an approximate 15 percent chance of survival. Vehicles traveling at lower speeds also have more reaction time, which helps prevent crashes. Designing for reduced vehicle speeds is especially important in urban, urban core and rural town contexts with higher levels of pedestrian and bicyclist activity.

Improving the level of service, QOS or performance for one roadside user mode may negatively impact those same elements for one or more of the other roadside modes. Space and service for roadside users may also compete for space within the constrained right-of-way cross-section environments. Although technical analysis driven by quantitative data provides useful information to the designer about the impacts of these design choices and modal interactions, no single process or tool can provide absolute choices for a “best fit” design solution that meets roadside user needs and balances them with traveled way user needs.

5.1.1.2 Roadside Uses

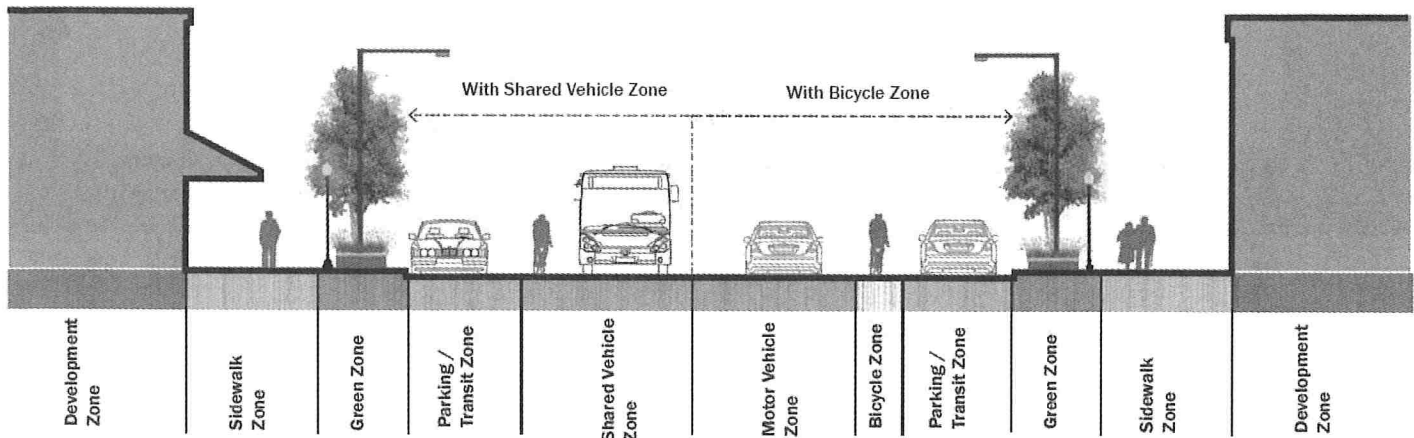
The roadside accommodates non-vehicular activity (typically walking and off-street bicycling) as well as the business and social activities of the adjacent land use context. It extends from the edge of the vehicular traveled way to the edge of the right-of-way, and it may abut buildings directly in urban and rural town settings, parking lots and fences in suburban settings, or open space in rural settings. The roadside also may contain private driveway approaches that must be carefully designed to ensure safe interactions between crossing pedestrians or bicyclists and motorized traffic or bicyclists in the traveled way.

In urban, suburban and rural town context zones, the public right-of-way most typically includes pedestrian facilities (sidewalk) between the back of curb (or edge of shoulder) to the front property line of adjoining parcels, supported by some level of landscaping. This space can also serve many other functions, such as stormwater collection and management, utility placement and transit access. A well-designed roadside is important to a roadway’s function as a “public place” in many urban, suburban and rural town contexts.

In urban and urban core areas with high levels of pedestrian use, the roadside often is divided into a series of zones that emphasize different functions, including frontage, throughway, furnishings and edge zones. (For more information on zones, see Chapter 2). On many corridors, the roadside also may include separate bicycle facilities, such as separated bicycle tracks, multi-use paths or exclusive cycle tracks. The function of roadside zones and the level of roadside use by pedestrians and bicyclists relate directly to the multimodal function of the corridor and the activities generated by the adjacent context.

In any context, the basic functions of the roadside are the accommodation of pedestrians, access to adjoining buildings and properties, traffic control devices (signs and posts, traffic signal equipment), and the provision of clear zones and space for above- and below-ground utilities and other roadside appurtenances. In urban and some suburban or rural town contexts, these basic functions may be shared with the activities generated by the adjacent land use and general community functions, which can include:

- Aesthetic features (such as landscaping, street trees, banners, public art);
- Pedestrian-supportive amenities (benches, trash receptacles, news racks, kiosks, parklets, public restrooms);

Exhibit 5-1. Cross section for typical urban/suburban Main Street.

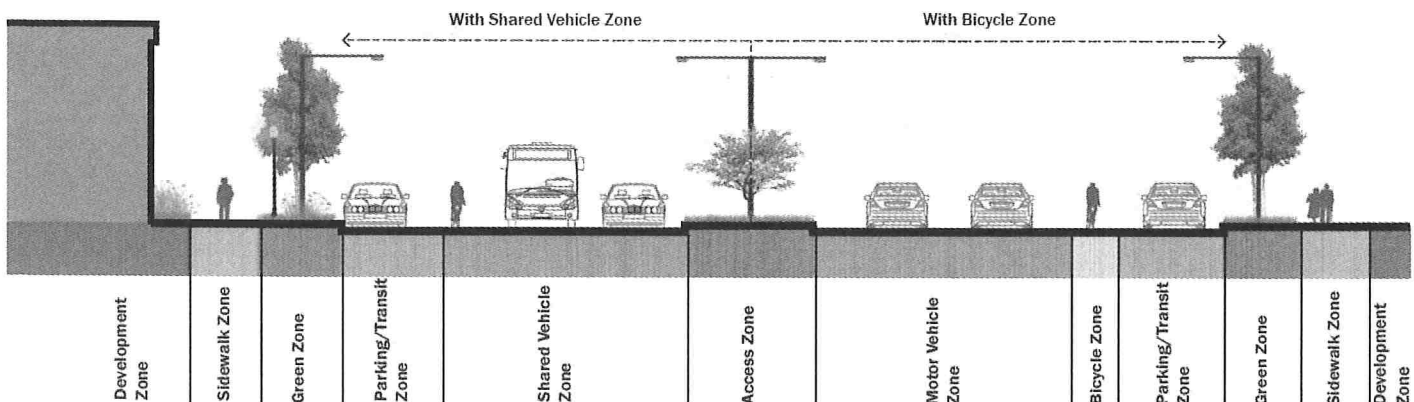
Source: North Carolina DOT (2012)

- Bicycle amenities (bicycle racks);
- Transit amenities (such as benches, shelters, waiting areas);
- Pedestrian-scale lighting;
- Sidewalk cafes;
- Fountains and water features;
- Plazas and seating areas; and
- Merchandise display and occasional public activities (such as farmers' markets or art shows).

Roadside functions vary greatly by context zone and land use activity. The width of certain elements of the roadside will vary by roadway depending on the existence or lack of on-street parking and the speed and volume of vehicular traffic on the roadway. For example, the width of the furnishings zone may vary, with one design factor being its use as a buffer from vehicles for non-motorized users. Variations in the width of the roadside are addressed in the design guidelines in the section on roadside width and functional requirements.

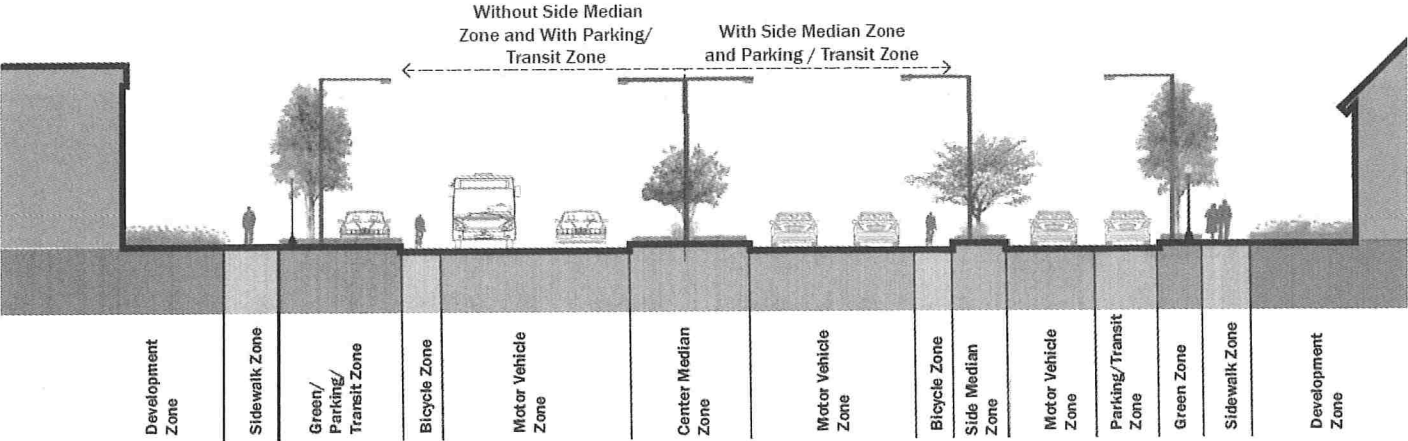
5.1.1.3 Roadside Types and Zones

Roadsides can take many forms and functions depending on the roadway and land use that they separate. Exhibits 5-1 through 5-11 illustrate differing traveled way roadside functions and

Exhibit 5-2. Cross section for typical urban/suburban avenue.

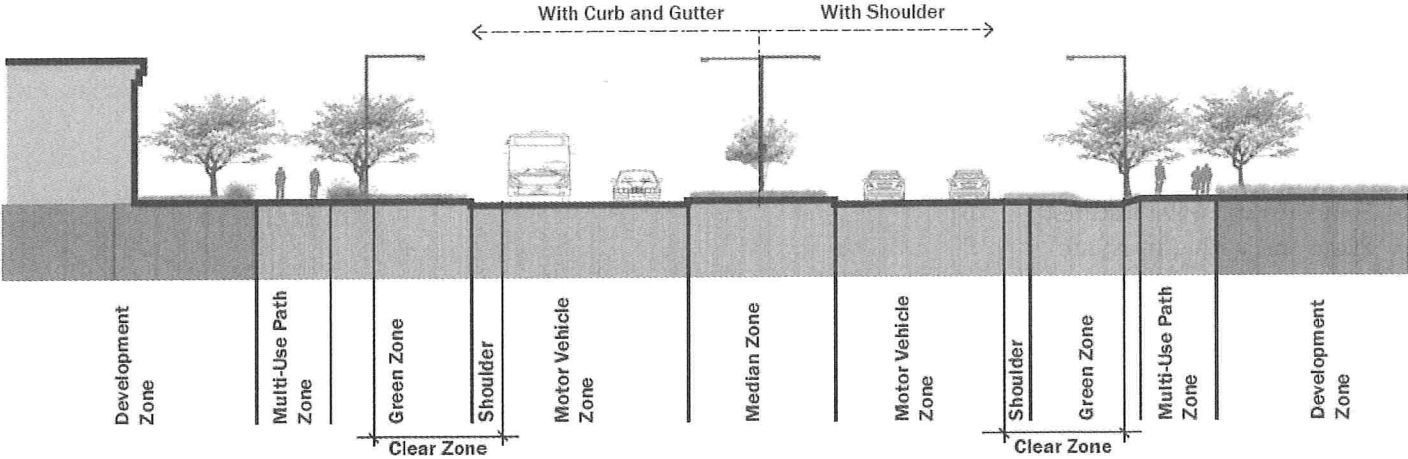
Source: North Carolina DOT (2012)

Exhibit 5-3. Cross section for typical urban/suburban boulevard.



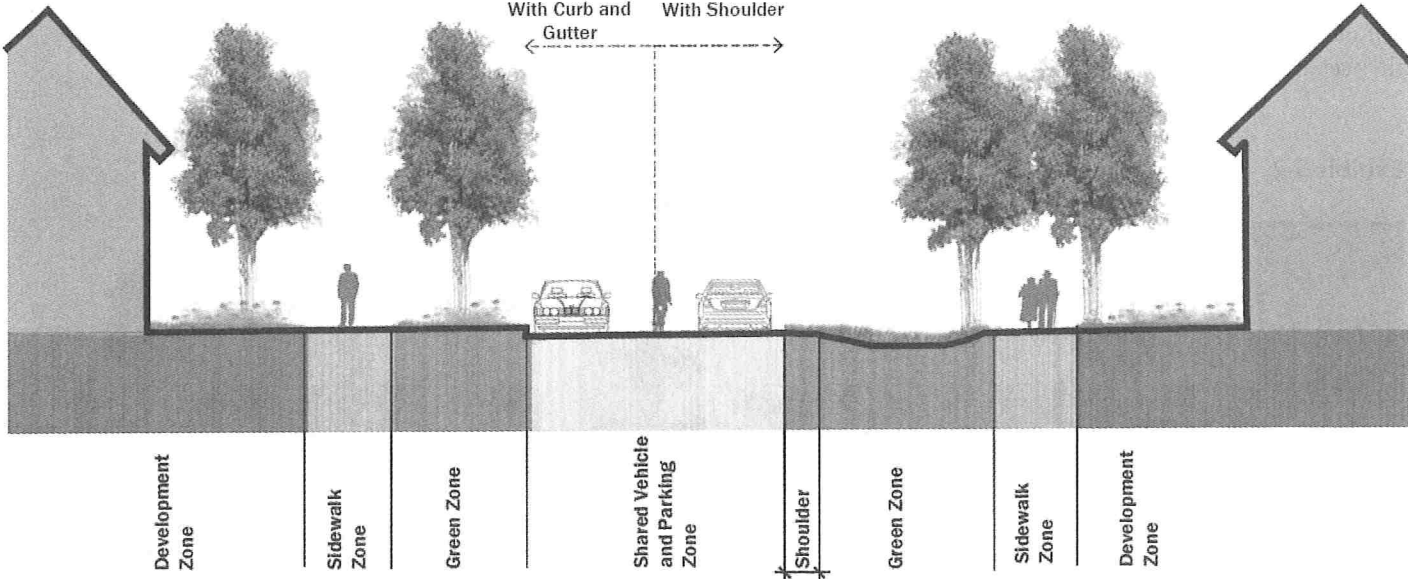
Source: North Carolina DOT (2012)

Exhibit 5-4. Cross section for typical urban/suburban parkway.



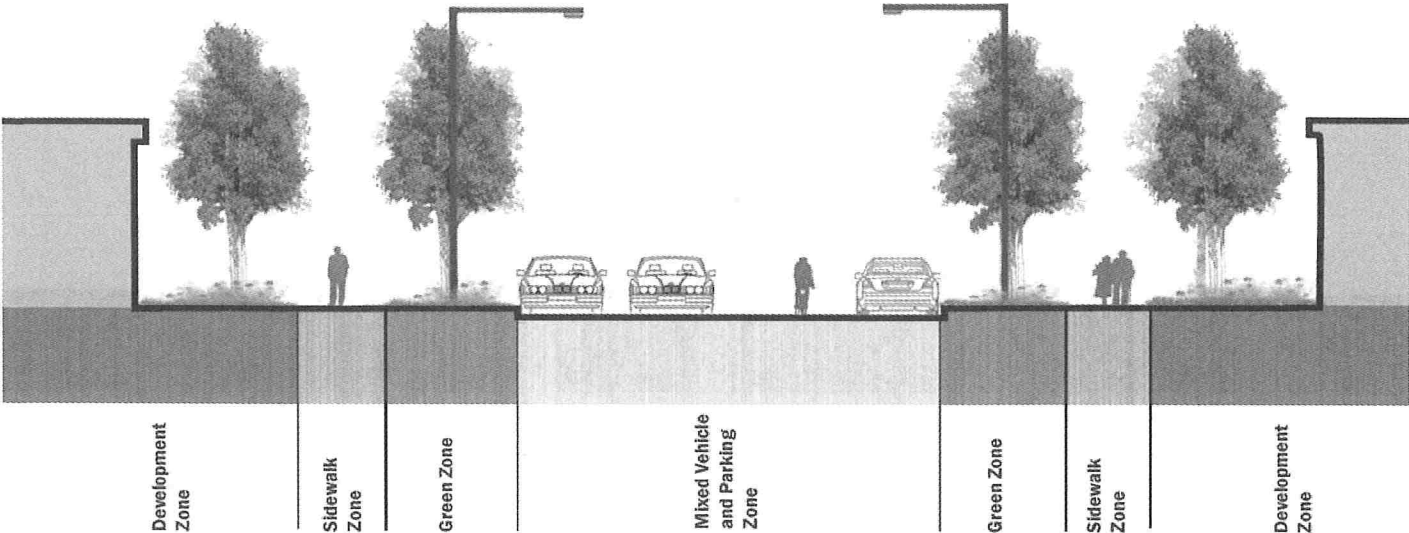
Source: North Carolina DOT (2012)

Exhibit 5-5. Cross section for typical local/subdivision residential street.



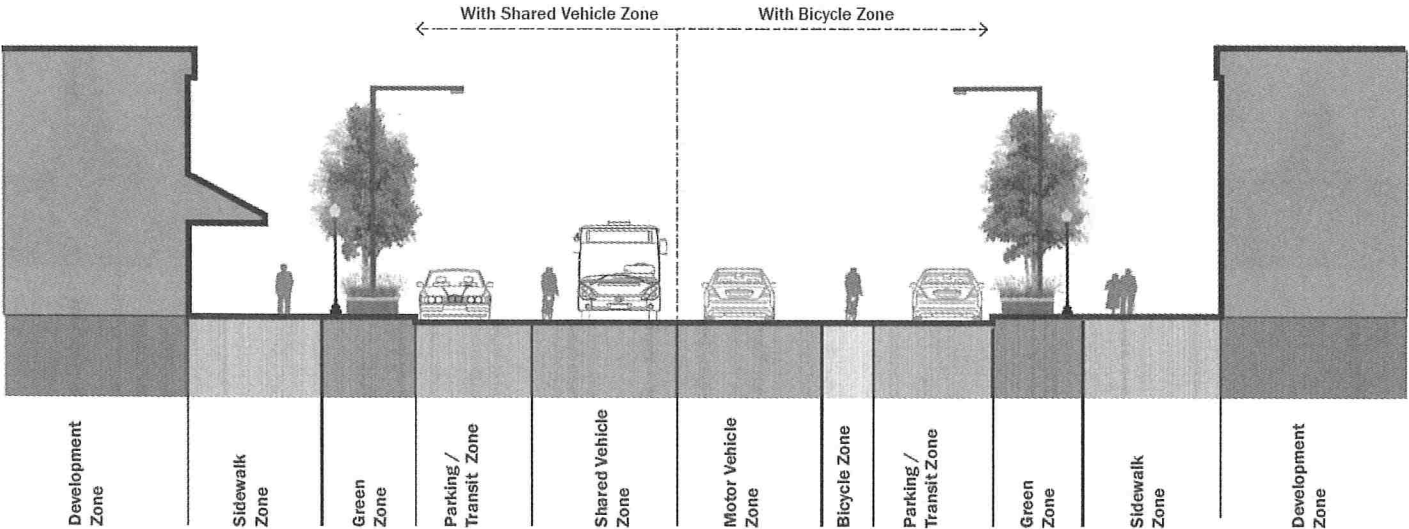
Source: North Carolina DOT (2012)

Exhibit 5-6. Cross section for typical local/subdivision office-commercial-industrial street.



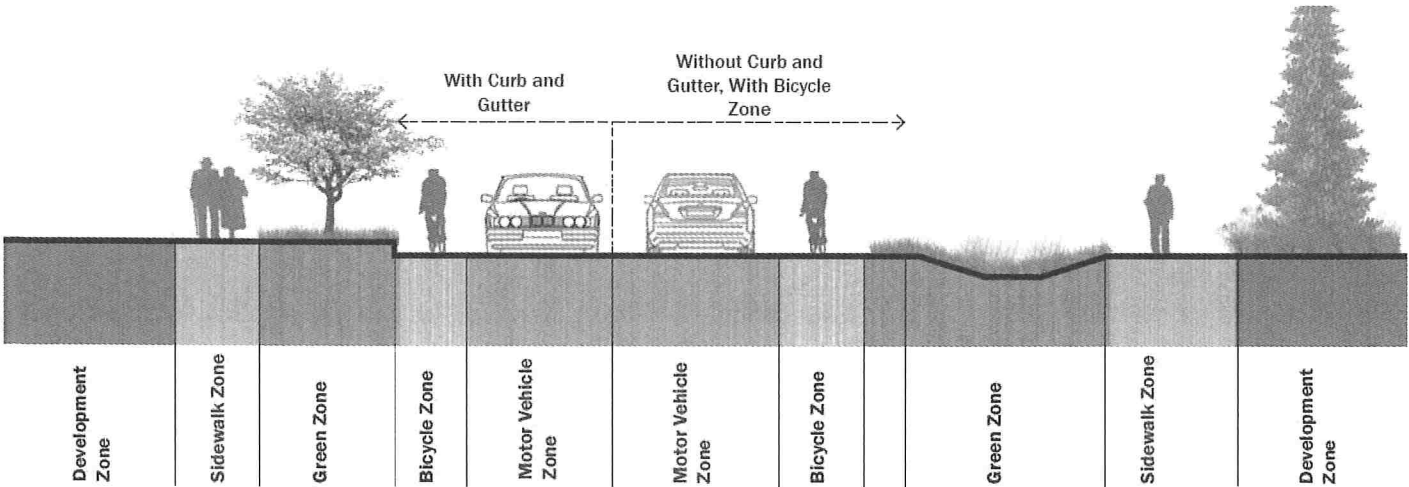
Source: North Carolina DOT (2012)

Exhibit 5-7. Cross section for typical rural town Main Street.



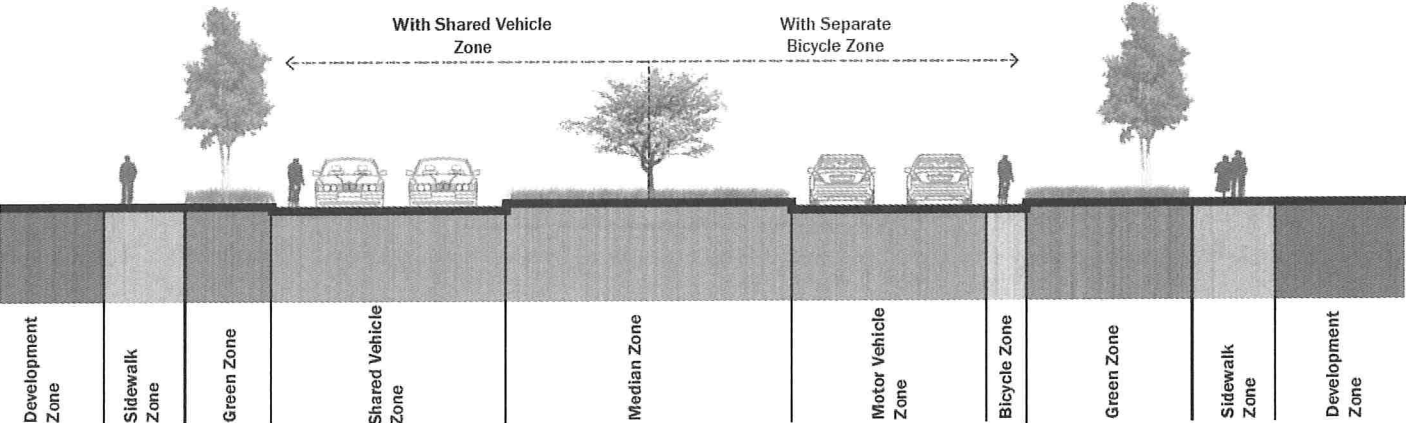
Source: North Carolina DOT (2012)

Exhibit 5-8. Cross section for typical rural avenue.



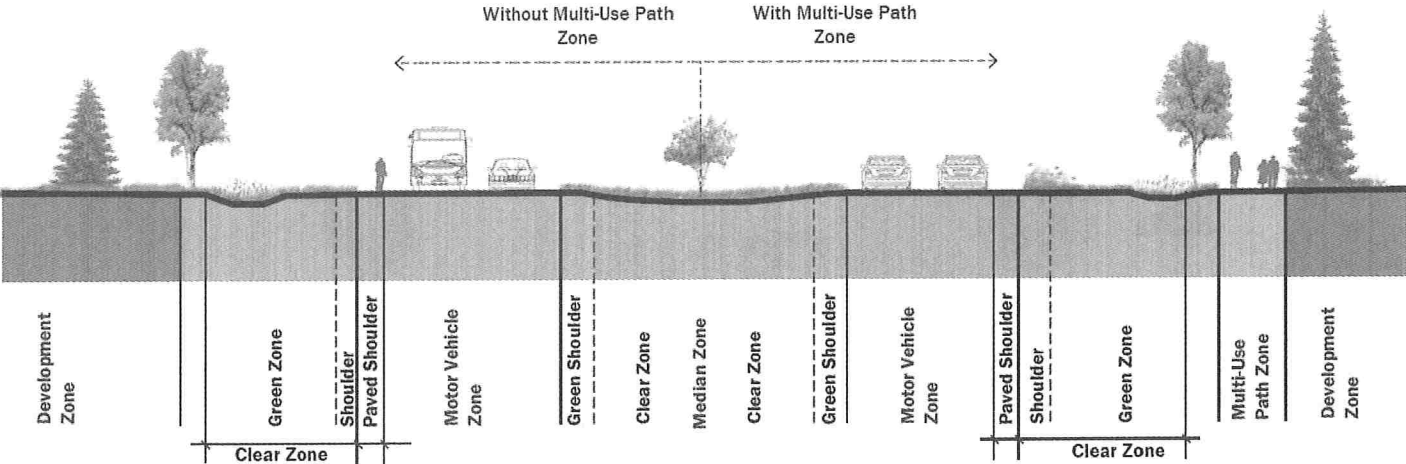
Source: North Carolina DOT (2012)

Exhibit 5-9. Cross section for typical rural boulevard.



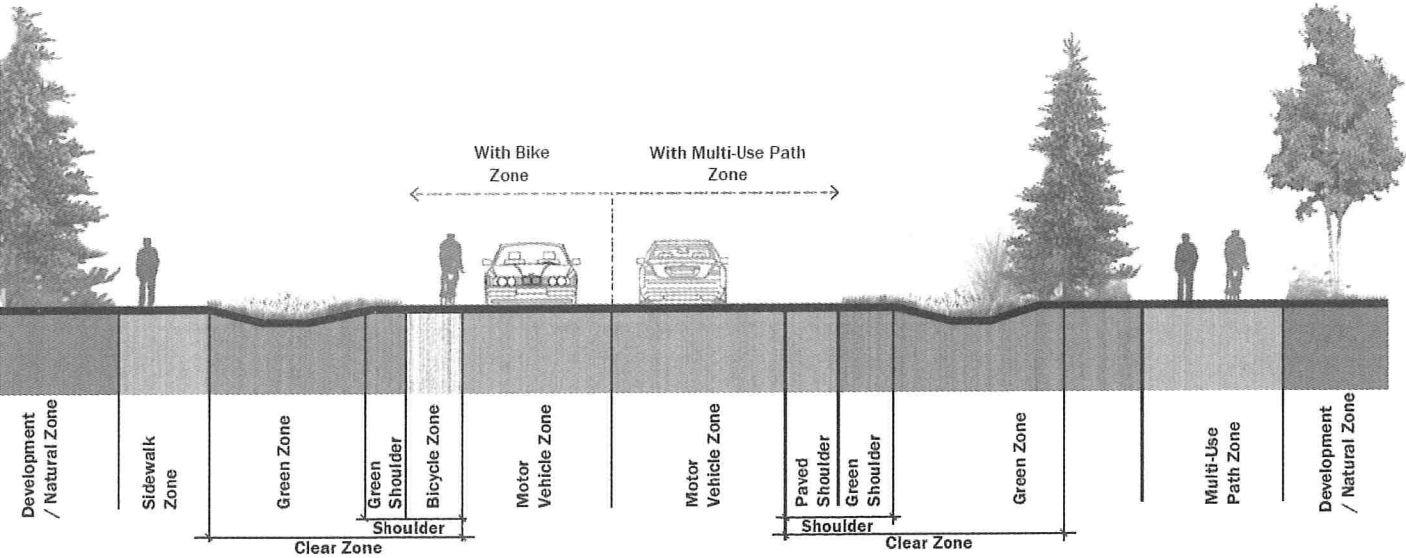
Source: North Carolina DOT (2012)

Exhibit 5-10. Cross section for typical rural parkway.



Source: North Carolina DOT (2012)

Exhibit 5-11. Cross section for typical rural road.



Source: North Carolina DOT (2012)

configurations across a range of roadway types in urban, suburban, rural and rural town contexts as included in the North Carolina DOT's *Complete Streets Planning and Design Guidelines* (2012). These eleven exhibits show the diversity of roadside uses and functions that may be appropriate for various roadside designs. Roadside elements, or zones, included in these cross sections include:

- Sidewalk zone,
- Bicycle zone,
- Green zone (landscaping/drainage) with and without curbs,
- Multiuse path zone,
- Shoulders (paved and unpaved), and
- Clear zone.

In urban core, urban, rural town and some suburban contexts, the roadside design becomes increasingly complex given the close proximity of building frontages and a high level of interaction between the roadside amenities and building activities. These settings generally incorporate wide pedestrian sidewalks; buffers between sidewalks and parking or moving traffic lanes; and other traveled way elements, such as bus stop shelters, benches, sidewalk cafes, street trees and landscaping. (For more information on urban roadsides, see Chapter 2 in this Guide, particularly Exhibits 2-6 and 2-7). Urban roadsides often are designed with four key functional zones in mind:

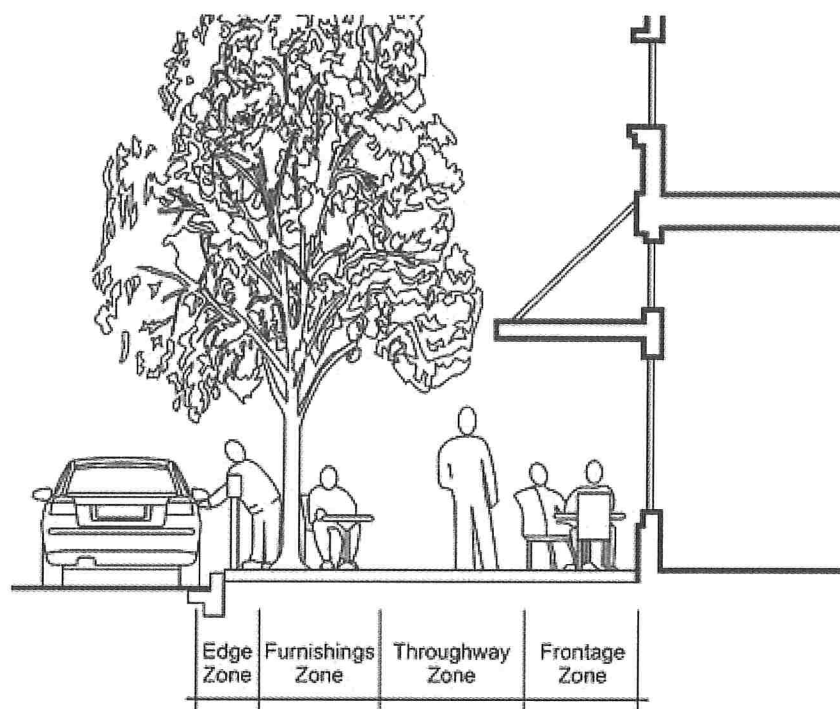
- **Edge zone.** This area, between the face of the curb and the furnishings zone, provides the minimum necessary separation between objects and activities in the roadside and vehicles in the traveled way;
- **Furnishings zone.** This area provides a buffer between pedestrians and vehicles, and may contain landscaping, public street furniture, transit stops, public signage, utilities and so forth;
- **Throughway zone.** The ADA establishes a minimum width for this area (sometimes called the “walking zone”), which must remain clear both horizontally and vertically for the movement of pedestrians (U.S. Access Board 2011); and
- **Frontage zone.** Defined by the distance between the throughway and the building front or private property line, this area is used to buffer pedestrians from window shoppers, appurtenances and doorways. The frontage zone may contain private street furniture, private signage and merchandise displays. Depending on the available width, it also can be used for street cafes. This zone is sometimes referred to as the “shy” zone.

Exhibit 5-12 illustrates the four zones using the example of a roadside in an urban commercial area.

5.1.2 Relationship of Roadside and Traveled Way Environments

A roadway design project may involve improvements to the roadside, to the traveled way, or to both. Even if a design project involves only one of these two realms, the proximity and interactions of the roadside with the traveled way make it essential to consider both realms during the design process. Land use context creates a third realm, which also is essential to consider in the design process because it informs the designer how the land use is served by, and relates to, all users of the roadside and the traveled way. Located between the traveled way and the adjacent land use context, the roadside must accommodate the uses, functions and activities of those realms as well as its own.

This chapter addresses design elements and criteria for the roadside that serves pedestrians of all ages and abilities, bicycle users in some settings, and land use needs in some contextual settings. Other special users may include persons in wheelchairs or scooters, skateboarders, and rollerbladers.

Exhibit 5-12. Key components of an urban roadside.

Source: Image courtesy of Community, Design + Architecture

Roadside users can be separated from the motorized vehicle traveled way by painted edge line markings where paved shoulders exist, by raised vertical curbs, by paved shoulders and vertical curbs, and by on-street parking. Where paved shoulders are provided but no all-weather or other roadside facilities are available to pedestrians or bicycle riders, these travelers may use the shoulder because they have no other option. Although shoulders are not substitutes for well-designed, separated pedestrian or bicycle facilities in the roadside, the need may occasionally exist to design shoulders as walkways or bikeways where roadside space or funding is constrained. The FHWA Guidance Memorandum *ACTION: Consideration and Implementation of Proven Safety Countermeasures* states that “walkable shoulders (minimum of 4 ft. stabilized or paved surface) should be provided along both sides of rural highways routinely used by pedestrians” (FHWA 2008). Bicycle use of shoulders is a common occurrence on many urban, suburban and rural roadways with shoulder facilities.

Design guidance for the traveled way, roadside and intersections are organized into three distinct chapters of this Guide, but all three design environments involve many interrelationships and multiple modal users. Therefore, the full right-of-way cross section and intersection design development process should be integrated as alternatives are developed and analyzed.

5.1.3 Multimodal Network Considerations

Project design usually takes place at a much smaller scale than the network level, but it is important that design of a multimodal project including roadsides understand the network role of the facility on which the project is located. A roadway’s functional classification (arterial, collector or local) as defined in the federal, state and regional transportation planning processes is a primary network consideration; however, these designations are based solely on motorized vehicle mobility. They do not address a facility’s role in the mobility of other modes and how the facility relates to the community and the adjacent land use context.

The design process for any roadside should recognize the role of that roadway in all related transportation plans. The project design should be guided by all related state, regional, sub-regional and neighborhood plans for the roadway facility in relation to context and community goals and values. The design of the individual roadside project, therefore, is guided by both its context and the combined multimodal performance of the network.

One difficult situation that is often encountered in the design of project roadsides on arterial roadways (and some collector roadways) is the need to balance the desires of local residents or communities to emphasize livability, character, walkability, bikeability, and other non-vehicle mobility goals versus the desires of transportation agencies to emphasize vehicle capacity or accommodation of projected vehicular travel demand. The designer should keep in mind that the roadside is the only traveled way for the pedestrian, and may be the only traveled way for bicyclists if separated lanes or other facilities are not provided.

Network goals and considerations for roadside users may be informed by several different levels of network plans, as noted in Exhibit 5-13. The role that the roadside may serve in each of these modal network levels will influence the design of that facility.

Multimodal accommodation can exist on any functional classification of roadway: arterial, collector or local. The Guide primarily addresses accommodation needs on arterial and collector roadways because it is typically on those facilities where the combination of user types and volumes, vehicle speeds and context interactions presents the most challenging conditions to a designer. However, designers should keep in mind that each roadway and roadside design is unique, and the ultimate design needs to address the context, objectives, priorities and design concept established for all aspects of the facility and corridor.

5.1.4 Balancing Safety Between Roadside Users and Traveled Way Users

Roadside safety concerns in urban contexts differ from those in rural contexts, where speeds are higher and most travel is by vehicle. In designing the roadside for traditional urban contexts,

Exhibit 5-13. Planning documents that address modal elements in roadside project design.

Type of Transportation Network Plan	Possible Roadside Modal Plan Elements			
	Transit	Bicycle	Pedestrian	Other Community Goals for Roadsides *
State Transportation Plan	X	X	X	
Regional Transportation Plan (MPO/TPO)	X	X	X	
Local Transportation Plan (County/City)	X	X	X	X
Bicycle/Pedestrian Plan (local, regional, state)		X	X	
Transit Agency Service Plan	X	X	X	X
Community Plan	X	X	X	X
Corridor Plan	X	X	X	X
Neighborhood Plan	X	X	X	X

* Land use (context), urban design, housing, community facilities, recreation, parks/open space, utilities economic development.

the designer is concerned about the safety of a wider range of users, including pedestrians on the sidewalk, and motorists, motorcyclists and bicyclists using the traveled way and/or roadside. The designer should consider the context of the roadway, including competing demands within limited rights-of-way and the peak periods when demand may be highest.

In urban areas, roadside safety is achieved by:

- Separating modes of different speeds and vulnerabilities to the extent possible by both space and time (e.g., bicyclists from pedestrians, pedestrians from vehicles, and bicyclists from vehicles when possible);
- Informing all users of the presence and mix of travel modes; and
- Providing adequate sight distance.

The most challenging aspect of this design process often lies in developing solutions to resolve the inherent conflicts that arise where modes of travel cross paths (e.g., driveways crossing pedestrian and bicycle paths in the roadside, pedestrians and bicycles mixing with motorized vehicles within intersections or other crossing locations). Providing for the roadside safety of the users in all contexts focuses on:

- Providing uniform and predictable designs and traffic control;
- Removing clearly hazardous roadside obstacles; and
- Establishing an appropriate vehicle operating target speed, which in turn controls the speed-related geometric design elements of the traveled way.

For detailed guidance on roadside design, the designer should be familiar with the concepts and guidance provided in the *Roadside Design Guide* (AASHTO 2011b) and *NCHRP Report 612: Safe and Aesthetic Design of Urban Roadside Treatments* (Dixon et al. 2008b).

5.1.4.1 Relationship of Vehicle Speed to Roadside Design

A person's decision to walk or ride a bicycle is influenced by many factors, including distance, perceived safety and comfort, convenience and visual interest of the route. In the roadside, pedestrians and bicyclists feel exposed and vulnerable when walking and riding directly adjacent to a high-speed travel lane, whether behind a standard vertical curb or on a shoulder. Vehicle noise, vehicle exhaust, and the sensation of passing vehicles reduce pedestrian and bicyclist comfort and increase their stress level. Factors that improve the comfort of pedestrians and bicyclists include increased separation distances from moving traffic and barrier protection from moving traffic or a reduction in vehicle operating speed. In urban and suburban environments, a buffer zone that improves pedestrian and bicyclist comfort can be achieved using the width of the edge and furnishings zones, landscaping and on-street parking.

5.1.4.2 Roadside Clear Zones

The application of a clear zone is most critical on high-speed (50 mph and above) roadways. Clear zones often are not fully implemented on low-speed (45 mph or below) urban thoroughfares with right-of-way constraints. In many situations, the vehicle safety hazard of roadside obstacles is substantially less in urban areas because of lower speeds, the presence of parked vehicles, or increased traveled way roadside separation from on-street bicycle lanes and buffers or shoulders.

The *Roadside Design Guide* (AASHTO 2011b) focuses on safety treatments that can minimize the likelihood of serious motorist injuries when vehicles leave the roadway. The principles and guidelines for roadside design presented in the AASHTO guide generally discuss roadside safety considerations for rural highways, Interstates and freeways. Speeds on these roadways are

generally higher, approaching or exceeding 50 mph, and vehicles are operating under free-flow conditions. Much of the information presented in the AASHTO guide applies to rural high-speed facilities, but Chapter 10 offers information on urban roadside practices. It presents the designer with considerations to enhance safety on uncontrolled access highways in urban or restricted environments with these typical conditions (AASHTO 2011b):

- Lower or lowering speeds;
- Dense abutting development;
- Limited rights-of-way;
- Closely spaced intersections and accesses to properties;
- Higher traffic volumes; and
- The presence of special users, including transit vehicles, delivery trucks, bicycles, and pedestrians (including persons with disabilities).

Chapter 11 of the *Roadside Design Guide* (AASHTO 2011b) provides information on mailboxes and mailbox pullout design. Chapter 12 discusses the application of the roadside safety concept on very low-volume roads and streets.

Written for use by design engineers and professionals involved in roadside safety, the *Roadside Design Guide* is not intended to be used as a standard or a policy statement. Designers are expected to use the AASHTO guide as one reference on which to build the roadside design criteria best suited to their particular location and projects. Knowledgeable design, practically applied at the project level, offers the greatest potential for a continually improved transportation system. The *Roadside Design Guide* provides the following information regarding roadside design relationships to pedestrian roadside users, and similar guidance could be applied to roadside bicycle users (AASHTO 2011b):

- The common practice in urban settings is to use curbs or curbs with gutters adjacent to the highway travel lanes or shoulders (when present) to provide separation of pedestrians from the traffic flow. Realistically, curbs have limited re-directional capabilities and these occur only at low speeds of approximately 40 km/h [25 mph] or lower. For speeds above 40 km/h [25 mph], the curb can influence driver behavior by providing positive guidance but does not provide a physical vehicle redirection function. Curbs alone may not be adequate protection for pedestrians on adjacent sidewalks or for shielding utility poles. In some cases, other measures may need to be considered.
- In urban conditions, a minimum lateral offset of 1.5 ft. should be provided beyond the face of curbs to any frangible obstructions. This minimum offset does not meet clear zone criteria, but simply enables normal facility operations which may help to:
 - Avoid adverse impacts on vehicle lane position and encroachments into opposing or adjacent lanes,
 - Improve driveway and horizontal sight distances,
 - Reduce the travel lane encroachments from occasional parked and disabled vehicles,
 - Improve travel lane capacity, and
 - Minimize contact from vehicle-mounted intrusions (e.g., large mirrors), car doors, and the overhang of turning trucks.
- Designers should strive for lateral offsets more appropriate for the off-peak operating speeds. Example preferred lateral offsets are identified in Section 10.1.3.1 of this chapter [in AASHTO 2011b]. At the higher-speed end of the rural-urban transition area or urban facilities, consideration should be given to providing a shoulder and offsetting any curbing to the back of the shoulder. The shoulders may be used to accommodate bicyclists and pedestrians where sidewalks are not provided.
- Sidewalks and pedestrian facilities, in general, do not pose a particular hazard to motorists. The safety concern for locating these facilities adjacent to the road is the risk to the pedestrians using the facilities.
- Providing safe facilities for pedestrians to walk is an obvious strategy for increasing pedestrian safety. The Green Book [AASHTO 2011a] recommends the use of sidewalks on urban streets, with sidewalk widths ranging between 4 ft. and 8 ft., depending on the roadway classification and nearby land use characteristics [see Exhibit 5-14].
- An additional feature of the roadside environment is a pedestrian buffer area (often referred to as a buffer strip). The pedestrian buffer is a physical distance separating the sidewalk and the vehicle travel way. Buffer areas often accommodate transit stops, street lighting, planting areas for landscape materials, and common street appurtenances including seating and trash receptacles. Buffer strips may be either

Exhibit 5-14. AASHTO-recommended sidewalk provisions by functional classification.

Roadway Classification	Side of Street	Dimension
Arterial	<ul style="list-style-type: none"> Both 	<ul style="list-style-type: none"> Border area (buffer plus sidewalk) should be a minimum of 8 ft. and preferably 12 ft. or more
Collector	<ul style="list-style-type: none"> Both sides of street for access to schools, parks, shopping Both sides of street desirable in residential areas 	<ul style="list-style-type: none"> 4 ft. minimum in residential areas 4 ft. to 8 ft. in commercial areas
Local	<ul style="list-style-type: none"> Both sides of street for access to schools, parks, shopping Both sides of street desirable in residential areas 	<ul style="list-style-type: none"> 4 ft. minimum in residential areas 4 ft. to 8 ft. in commercial areas, although additional width may be desirable if roadside appurtenances are present.

Source: Compiled from the Green Book (AASHTO 2011a)

planted or paved and are encouraged for use between urban roadways and their companion sidewalks. On-street parking is a portion of the traveled way, but it can also serve as an important pedestrian buffer in some contexts.

- Common strategies for eliminating or minimizing motorized vehicle-pedestrian crashes at roadside locations are provided in Table 10.5 [of the *Roadside Design Guide*] as follows:

Purpose:	Strategy:
Reduce motorized vehicle-pedestrian crash likelihood at roadside locations	<ul style="list-style-type: none"> Offset pedestrian locations away from travel way with pedestrian buffers Physically separate pedestrians from travel way at high-risk locations Improve sight distance by removing objects that obscure driver or pedestrian visibility Provide continuous pedestrian facilities Install pedestrian refuge medians and/or channelized islands (see [separate] section on medians and islands)
Reduce severity of motorized vehicle-pedestrian crashes at roadside locations	<ul style="list-style-type: none"> Reduce roadway design speed / operating speed in high pedestrian volume locations

- Bicycle facilities consist of road and roadside features intended for bicycle operation. These facilities may include standard lanes, wide outside lanes, and bicycle lanes in the traveled way. The roadside may incorporate separated bike lanes, off-road bicycle paths and shared-use paths. Accompanying bicycle facilities in the roadside may include bicycle hardware such as bicycle racks. Wide shoulders and bicycle lanes provide an additional “clear” area adjacent to the traveled way, so these features could potentially provide a secondary safety benefit for motorists, provided bicycle volumes are low, and can be included as part of the clear zone. These bicycle facilities will also further separate the motorized vehicle from any roadside obstructions and improve the resulting sight distance for motorized vehicle drivers at intersecting driveways and streets.
- Bicycle racks are commonly made of steel or other metals, and are typically bolted to the ground to secure locked bicycles from potential theft. These features are not designed to be yielding should a run-off-road event occur. Making such features yielding would potentially minimize the core function of these features, to provide a secure location for locking up bicycles. Thus, a potentially more desirable alternative may be to encourage the placement of these features outside of the clear zone on higher-speed roadways.
- One on-roadway safety feature that is becoming more prevalent nationwide on facilities experiencing a significant number of runoff-the-road crashes is the use of rumble strips to supplement pavement edge lines. These indentations in the roadway shoulders alert motorists through noise and vibration that their vehicles have departed the traveled way and afford them an opportunity to return to and remain on the roadway safely. While these features are typically used in rural highway settings, there may be contexts in suburban settings where this treatment is applied.

NCHRP Report 612: Safe and Aesthetic Design of Urban Roadside Treatments (Dixon et al. 2008b) discusses the many challenges that are encountered when designing roadway projects in urban areas or rural towns. This report recognizes that, although arterial and collector roadways are typically designed to move vehicles as quickly and efficiently as possible, in many locations these roadways are the centers of communities that have developed around them. The report also calls attention to the fact that communities are increasingly requesting that these facilities be redesigned using roadside solutions that enhance the appearance and, in many cases, the functional uses of the roadway for all users of the right-of-way. *NCHRP Report 612* recognizes that the urban roadside environment is complex and often constrained, thereby making it difficult for a designer to achieve an acceptable clear zone, free of fixed objects. As a result, a lateral offset that enhances roadway operations is recommended, recognizing that this offset does not represent a safe placement for rigid roadside objects (Dixon et al. 2008b).

5.1.5 Considerations in Urban, Suburban and Rural Contexts

Understanding context is considered a necessary element of effective multimodal roadway design. This is especially true for the roadside component of the right-of-way because of the interactions of non-motorized users (who share the roadside and directly interact with the traveled way on one side and interact with land uses on the other side). This section of Chapter 5 summarizes design considerations in urban, suburban, and rural contexts. A broader discussion of design considerations for low- and intermediate-speed (45 mph or less) roadways and streets that serve a mix of user modes is provided in Chapter 2 of this Guide.

The design guidance presented throughout this Guide requires a thorough understanding of how the current and future context of a project area can impact multimodal activity within and adjacent to the project limits. The application of context also requires a designer to know how to apply design controls and criteria to support beneficial interaction between the roadside, the traveled way, and the existing and planned multimodal activity generated by adjacent land uses and local modal networks.

Designing for low- and intermediate-speed multimodal roadways requires an expanded understanding of context. Context depends highly on many aspects of land use, including building and site design, which can provide support for integrated pedestrian, bicycle and transit activities in the roadside environment. The roadside design process should recognize land use as an important contributor to overall project context and as a major factor in the selection of design criteria related to the levels of motorized and non-motorized travel produced by the land use. Land use also factors significantly in selecting and assembling components of the roadside cross section.

Differing land uses have differing needs for design elements such as clear sidewalk space, landscaping, street furniture, bicycle parking and so forth. Commercial uses tend to generate higher volumes of pedestrian and bicycle travel than do uses such as office or industrial. Commercial areas also typically have a higher volume of delivery trucks and buses, and there is usually a higher turnover of on-street parking than residential areas.

5.1.5.1 Selecting Context Zones in Roadside Design

Context helps guide the selection and prioritization of basic design elements and criteria for low- and intermediate-speed roadways with a mix of motorized and non-motorized users. This Guide has defined a group of five context zones that can be used as a primary initial consideration in selecting the design elements and criteria for multimodal roadways (see Chapter 2, Exhibit 2-4). Deciding which context zone to use for a particular project, or for a project that involves a combination of contexts, can be challenging. Variations in land use or

modal variations within each context zone should be considered by the designer in developing cross sections and design elements.

Guidelines for selecting the context to be used to inform the roadside design process are essentially the same as those used for the traveled way design process. Key considerations for projecting roadside user demands include:

- Consider both existing conditions and future plans, recognizing that roadway improvements often last longer than development;
- Assess area plans and review general, comprehensive and specific plans, zoning codes and community goals and objectives, which may provide detailed guidance on the vision for the area;
- Compare the area's predominant land use patterns, building types and land uses to the characteristics presented in Exhibit 2-4;
- Pay particular attention to residential densities and building type, commercial floor area ratios and building heights;
- Consider dividing the area into two or more context zones if a range of land use characteristics suggests multiple context zone types;
- Identify current levels of pedestrian, bicycle and transit activity; and
- Estimate future levels and circulation needs based on the type, mix and proximity of land uses.

5.1.5.2 Main Streets as a Special Context

Main streets are a unique type of context. Typically found in smaller towns and villages in rural settings, urban cores and urban neighborhood centers, main streets vary from community to community, but some universal characteristics can be identified. They are usually short, walkable segments of arterial or collector roads or streets, often only a few blocks in length. They also may fall within a grid or interconnected system of local streets, serving the commercial center of town with short blocks, minimal or no driveways and buildings often served by alleys.

Land uses on main streets consist of compact, mixed-use development, usually with a strong retail and entertainment emphasis on the ground floors and with office or possibly residential uses on the upper floors. Buildings are typically one to three stories (or taller in an urban core) and are oriented to the street without setback. Buildings generally are closely spaced, with available parking on-street or in lots or garages behind or to the side of the buildings.

The design of main streets often includes wide roadsides that support active uses such as street cafes, social interactions, strolling and window-shopping. By tradition and design, main streets are pedestrian friendly and may have historic design features, street furniture, landscaping, public spaces, and possibly public art. Main streets are typically low-speed facilities with target operating speeds no higher than 30 mph. They may employ curb extensions that provide for shorter crossing distances and additional space for plantings, street furniture and traffic calming.

Roadside design features include an appropriate width to accommodate anticipated levels and types of activity. The provision of distinct roadside zones is considered a key element of main streets. The clear pedestrian throughway should be wide enough, at a minimum, to allow two people to walk side-by-side and often is wide enough to allow pairs of people to pass one another. The frontage zone should allow for window shopping, seating, displays and pedestrian activity at building entrances. The furnishings zone may need to accommodate many distinct functions, including street trees, planting strips, street furniture, utilities, bicycle racks, public art and possibly transit stops. If community plans call for street cafes, then the furnishings zone should also be designed to accommodate them.

If the traveled way provides on-street parking, the edge zone will need to accommodate car door openings, signing, lighting and possibly parking meters. Lighting may serve a dual purpose

for the roadside and traveled way, or the design may incorporate separate pedestrian-scaled decorative lighting.

5.1.6 Design Controls for the Roadside

AASHTO guidelines identify functional classification and design speed as primary factors in determining roadway design criteria. The Green Book (AASHTO 2011a) separates its design criteria by both functional classification and urban and rural context. The primary differences between contexts are the speed at which the facilities operate, the mix and characteristics of the users and the constraints of the surrounding context.

In addition to functional classification, speed and context, AASHTO presents other design controls and criteria that form the basis of its recommended design guidance. Design controls for the traveled way design are addressed in Chapter 4 of this Guide. This chapter focuses on design controls related to pedestrian and bicycle users as identified in the Green Book.

The Green Book provides this guidance on designing for pedestrians and bicyclists (AASHTO 2011a):

Interactions of pedestrians with traffic are a major consideration in highway planning and design. Pedestrians are a part of every roadway environment, and attention should be paid to their presence in rural as well as urban areas. The urban pedestrian, being far more prevalent, more often influences roadway design features than the rural pedestrian does. Because of the demands of vehicular traffic in congested urban areas, it is often very difficult to make adequate provisions for pedestrians. Yet provisions should be made, because pedestrians are the lifeblood of our urban areas, especially in the downtown and other retail areas. In general, the most successful shopping sections are those that provide the most comfort and pleasure for pedestrians. Pedestrian facilities include sidewalks, crosswalks, traffic control features, and curb cuts (depressed curbs and ramped sidewalks) and ramps for the older walkers and persons with mobility impairments. Pedestrian facilities also include bus stops or other loading areas, sidewalks on grade separations, and the stairs, escalators, or elevators related to these facilities [...].

The bicycle is an important element for consideration in the highway design process. The existing street and highway system provides most of the network needed for bicycle travel. While many highway agencies allow bicycles on partially access controlled facilities, most highway agencies do not allow bicycles on fully access controlled facilities unless no other alternative route is available. Improvements such as the following, which generally are of low to moderate cost, can considerably reduce the frequency of crashes on a street or highway and provide for bicycle traffic; paved shoulders, wider outside traffic lanes (14 ft. minimum) if no shoulders exist, bicycle compatible drainage grates, adjusting manhole covers to the grade, and maintaining a smooth, clean riding surface.

The Green Book also provides this guidance to the designer on bicycle accommodation (AASHTO 2011a):

- At certain locations or in certain corridors, it is appropriate to further supplement the existing roadway system by providing specifically designated bikeways for either exclusive or non-exclusive bicycle use;
- To provide adequately for bicycle traffic, the designer should be familiar with bicycle dimensions, operating characteristics, and needs as these factors determine acceptable turning radii, grades, and sight distance; and
- In many instances, design features of separate bike facilities are controlled by the adjoining roadway and by the design of the highway itself.

Pedestrian characteristics that serve as design controls include walking speed, walkway capacity and the needs of persons with disabilities. The Pedestrian Facilities Guide (AASHTO 2004b) and Bicycle Guide (AASHTO 2014b) expand significantly on the Green Book guidance, presenting factors, criteria and design controls. The Pedestrian Facilities Guide emphasizes pedestrians and bicyclists as a design control in all contexts, but particularly in the urban core, urban, suburban and rural town contexts.

Roadways with existing or anticipated high levels of pedestrian and bicycle usage should provide appropriate roadside and bicycle facilities (in the traveled way and/or roadside) in project

design. These facilities must be coordinated with the other design elements in the traveled way, and be sensitive to project context. As a result, in some projects the design requirements for bicyclists and pedestrians may function as design controls, significantly influencing the prioritization of design elements for all users of the right-of-way. For example, requirements for bicycle lanes may be considered a higher priority than a landscaped median, on-street parking or even vehicle travel and turn lanes.

A fundamental expectation in roadway design is that all users will be accommodated safely. In the roadside environment, the users typically include pedestrians and bicyclists with a wide range of ages and abilities. The characteristics of these varied roadway users are important controls that influence the physical design of a roadside. Early in the process, the designer should determine the estimated demand and composition of users anticipated for the facility. Accounting appropriately for all user characteristics is essential for designing a safe and efficient project. Experience demonstrates that when human and vehicular factors are properly accommodated, the safety and effectiveness of the overall roadway system is greatly enhanced. Consideration of roadway users' characteristics and selection of appropriate accommodations also can influence the roadway's effectiveness for businesses and residential users, the economic health of the region, the physical health of the population, and the quality of the built and natural environment.

The Massachusetts DOT's *Project Development and Design Guide* (Massachusetts Highway Department 2006) provides a good overview of pedestrian and bicycle users and their characteristics, which is summarized in the following sections.

5.1.6.1 Pedestrians

All travelers are pedestrians at some point during their trip, and pedestrians are a part of every roadway environment. In some cases pedestrians are regular users of the roadway while in others, pedestrians may be using the roadway in emergency circumstances, such as accessing a disabled automobile. Pedestrian facilities include sidewalks, paths, crosswalks, stairways, curb cuts and ramps, and transit stops. In lower-speed and lower-volume contexts, pedestrians may use the shoulder or even share the road to complete a trip.

Designers should understand that no single "design pedestrian" exists and that the transportation network should accommodate a variety of pedestrians, including people with disabilities. For example, children perceive their environment differently from adults and are not able to judge how drivers will behave. Children usually walk more slowly, have a shorter gait, and have a lower eye height than adults. Older adults may:

- Require more time to cross streets,
- Desire surfaces that are more predictable,
- Benefit from handrails in steep areas, and
- Require places to rest along the route.

Based on information in the most recent U.S. Census, almost 20 percent of the pedestrian population has some disability, and that number is likely to grow as the population ages. People with vision impairments require audible and tactile cues to safely navigate sidewalks and crosswalks. People with limited cognitive abilities may rely on symbols and take longer to cross the street. People using wheelchairs or scooters may travel across an intersection faster than people who are walking, but it is more difficult for drivers of high-profile vehicles to see people in wheelchairs or on scooters. It is important to recognize that pedestrians exhibit a wide range of physical, cognitive and sensory abilities, but they all make up the "pedestrians" that a designer needs to accommodate.

When estimating pedestrian travel between activity centers (i.e., residence to school, parking to store), distance is the primary factor in the initial decision to walk. Most people are willing to

walk for 5 min. to 10 min. at a comfortable pace to reach a destination (typically a distance of up to 0.4 mile). Although longer walking trips are possible, for most people 1.0 mile is generally the longest distance that they are willing to walk on a regular basis.

The designer also should ensure that pedestrian network connectivity and safe crossings are provided between activity centers. In addition to the characteristics described above, the spatial dimensions of pedestrians and their operating characteristics are key critical aspects that influence the detailed design elements of pedestrian facilities.

5.1.6.2 *Spatial Needs of Pedestrians*

Pedestrians require a certain amount of physical space in order to maneuver comfortably. The space requirements of pedestrians influence the ability for individuals to freely select their speed and the carrying capacity of a pedestrian facility. The HCM (TRB 2016b) provides methodologies for evaluating how a pathway serves the demand placed upon it, or how wide a sidewalk should be for a given demand. Space requirements also are influenced by the characteristics of those who use wheelchairs or other assistive devices as outlined in the PROWAG (U.S. Access Board 2011).

A simplified body ellipse of 2.0 ft. by 1.5 ft. (for an area of 3.0 sq. ft.) is used as the basic clear space for a single pedestrian. This area represents the practical minimum space required for standing pedestrians, although a single person using crutches, a service animal, or a walker typically requires 36 in. (3.0 ft.) clear width. The clear space for a person sitting in a stationary wheelchair is generally understood to be 2.5 ft. by 4.0 ft. (or 10.0 sq. ft.), although people using scooters and power chairs may require even more space. In evaluating a pedestrian facility, an area of 8.0 sq. ft. typically is considered adequate to allow a buffer zone for each pedestrian, with approximately twice that needed for each person using a wheelchair or a white cane.

These dimensions indicate that a 3-ft. pathway is adequate for single-file pedestrian flow in one direction, in the absence of vertical obstructions along the route. To allow free passing of pedestrians, a walkway that is at least 5-ft. wide and clear of obstructions is required.

Walking is often a social activity, and frequently pedestrians walk in pairs or groups. To account for this common behavior, it may be desirable to design facilities that enable two people to walk or ride their wheelchairs abreast, requiring approximately 6 ft. of width. In areas with high pedestrian traffic, greater widths are desirable.

5.1.6.3 *Bicyclists*

Safe, convenient and well-designed facilities are essential to encourage bicycle use. Roads designed to accommodate bicyclists with moderate skills will meet the needs of many riders, although many occasional and recreational riders prefer separated facilities such as cycle tracks, sidepaths or shared-use paths. Young children are primarily the bicyclists who may require special consideration, particularly on neighborhood streets, in recreational areas, and close to schools. Moderately skilled bicyclists may be served by:

- Extra operating space when riding on the roadway (e.g., bicycle lanes, usable shoulders or wide curb lanes);
- Low-speed streets (where cars share travel lanes); and
- A network of designated bicycle facilities (e.g., bicycle lanes, side-street bicycle routes and shared-use paths), supplemented by paths for bicyclists that supplement the roadway network and generally also serve other non-motorized users.

The design of roads for bicycling should consider these factors:

- Providing width sufficient for motorists to pass bicyclists without changing lanes on high-speed or high-volume roadways;

- Removing roadway obstacles that could cause bicyclists to fall;
- Using guide signs and/or pavement markings to direct bicyclists to scenic and low-traffic routes; and
- Providing signalized crossings of major roads when warranted for those who are not comfortable making left turns in heavy traffic.

When bicycles are used on public streets and roads, bicyclists generally are subject to the same traffic rules as motorized vehicle operators.

5.1.6.4 Spatial Needs of Bicyclists

The bicyclist's operating characteristics include required width, angle of lean when negotiating curves, sight distances, and clear zones. Clear width requirements may vary somewhat depending on bicycle type. Typically, bicyclists require a clear width of at least 40 in. A clear width of at least 48 in. is necessary to accommodate bicycles with trailers or adult tricycles. The required height of the operating space is 100 in.

An operating space of 4 ft. is assumed as the minimum width for one-way bicycle travel. Where motorized vehicle traffic volumes, truck and bus volumes, or speeds are high, a more comfortable operating space of 5 ft. to 6 ft. is desirable. Where bicyclists travel adjacent to on-street parking, a 5 ft. to 6 ft. operating space also is desirable to provide bicyclists space to avoid car doors that may open into the travel lane.

Critical design considerations include the minimal surface contact between bicycle tires and the ground and the susceptibility of bicycle tires to damage. The minimal tire contact means that longitudinal seams and cracks, sand, mud, wet leaves, metal utility covers and decking, and skewed railroad tracks can precipitate a crash. Longitudinal cracks as narrow as 1/4 in. and surface edges higher than 1/2 in. can cause loss of control. Bicyclists may be forced to swerve to avoid road debris or obstacles, using maneuvers that are unexpected by motorized vehicles sharing the same lane. Placement of obstacles in the travel path of bicyclists should be avoided.

5.1.7 Considerations Related to Users with Disabilities

The Green Book notes that roadway "designs with features for persons with disabilities can greatly enhance the mobility of this sector of our society. To provide adequately for persons with disabilities, the designer should be aware of the range of disabilities to expect so that the design can appropriately accommodate them. The designer is cautioned to adequately review all local and national guidelines for proper compliance with applicable rules and regulations" (AASHTO 2011a). The U.S. Access Board produces the primary guidelines that address regulations for designing facilities to accommodate users with disabilities.

In 2010, the U.S. Access Board published the *ADA Standards for Accessible Design* (U.S. Access Board 2010), which provides guidelines based on standards issued earlier that year by the U.S. DOJ (2010a). Subsequently, the Board published *Proposed Guidelines for Pedestrian Facilities in the Public Right-of-Way* (PROWAG) in 2011, and in 2013 the Board published a supplement titled *Accessibility Guidelines for Pedestrian Facilities in the Public Right-of-Way; Shared-Use Paths*, which broadened the coverage of its guidelines to encompass shared-use paths used by pedestrians, bicyclists and others for transportation or recreation (U.S. Access Board 2011, U.S. Access Board 2013). The 2013 supplementary guide added new provisions tailored to shared-use paths that cover grade, cross slope, surfaces and protruding objects. At the time of publication of this Guide, the U.S. Access Board had not issued a final PROWAG rule for either the 2011 pedestrian facilities guidelines or the 2013 shared-use path guidelines.

The PROWAG will become an enforceable standard only after the Board publishes a final rule, and only after the U.S. DOJ and/or the U.S.DOT adopt the final guidelines into their respective ADA and Section 504 regulations. Until that time, the U.S. DOJ 2010 ADA Standards and the U.S.DOT 2006 ADA and Section 504 Standards provide enforceable standards applicable to the public right-of-way. Where these standards do not address a specific issue in the public right-of-way, FHWA encourages public entities to look to the U.S. Access Board's draft 2011 and 2013 PROWAG guidelines for best practices.

This Guide cites the draft PROWAG in anticipation of final PROWAG being adopted as the enforceable standard in the near future. Public entities and/or recipients of federal financial assistance are responsible for complying with the current ADA and Section 504 accessibility standards and/or demonstrating equivalent facilitation. Several jurisdictions have applied the draft PROWAG as an alternative to, or equivalent facilitation for, the adopted ADA standards because the PROWAG provides more specific coverage of accessibility issues in the public right-of-way. Jurisdictions that have adopted the draft PROWAG as their standard should consistently apply all provisions of the draft PROWAG.

The PROWAG calls for a pedestrian access route to provide a 4-ft. minimum continuous clear width, a maximum grade consistent with the road grade, a maximum 2-percent cross slope, and a "firm, stable, and slip-resistant" surface (U.S. Access Board 2011). These accessibility guidelines greatly influence the design strategies for all pedestrian facilities, including sidewalks, shared-use paths, street crossings, curb ramps, signals, street furniture, transit stations, on-street parking, loading zones and more. In this Guide, key elements of PROWAG guidance as presented in *Achieving Multimodal Networks: Applying Design Flexibility and Reducing Conflicts* (FHWA 2016a) are summarized in Chapter 4 in the section titled "Users with Disabilities in Multimodal Design."

5.1.8 Considerations Related to an Aging Population

In coming decades, the proportion of the U.S. population aged 65 years and older will increase significantly. This means that a steadily increasing proportion of pedestrians and bicyclists will experience declining vision; slowed decision making and reaction times; exaggerated difficulty when dividing attention between traffic demands and other important cognitive tasks; and reductions in strength, flexibility, and general fitness. Although the effects of aging on people as drivers, pedestrians and bicyclists are highly individual, design practices that explicitly recognize these changes will better serve this growing segment of the nation's population.

The Green Book notes that a pedestrian's age is an important factor that may explain behavior that leads to collisions between motorized vehicles and pedestrians (AASHTO 2011a). Other observations include:

- Older pedestrians may be affected by limitations in sensory, perceptual, cognitive, or motor skills;
- Pedestrian collisions also can be related to the lack of sidewalks, which may force pedestrians to share the traveled way with motorists; and
- Sidewalk construction should be considered as part of any urban/suburban street improvement.

The Green Book also suggests the following measures as having potential to aid older pedestrians (AASHTO 2011a):

- Use simple designs that minimize crossing widths and minimize the use of more complex elements such as channelization and separate turning lanes;
- Assume lower walking speeds;

- Provide median refuge islands of sufficient width at wide intersections;
- Provide lighting and eliminate glare sources at locations that demand [multifocused] information gathering and processing;
- Consider the traffic control system in the context of the geometric design to assure compatibility and to provide advance warning or guide signs for situations that could surprise older pedestrians;
- Use enhanced traffic control devices;
- Provide oversized, retroreflective signs with suitable legibility;
- Consider increasing sign letter size and retroreflectivity to accommodate individuals with decreased visual acuity;
- Use properly located pedestrian signals with large indications;
- Provide enhanced markings and delineation; and
- Use repetition and redundancy in design and in signing.

5.1.8.1 Pedestrians

According to the *Older Driver Highway Design Handbook* (FHWA 1998), for pedestrians, diminished capabilities related to aging may make it more difficult to negotiate intersections. Individual concerns will vary, but may include:

- Decreased visual acuity,
- Increased risk of falls,
- Slowed walking and crossing speeds, and
- Decreased ability to judge safe gaps and avoid turning vehicles.

Moreover, loss of physical strength, joint flexibility, agility, balance, coordination and motor skills, and stamina can contribute to difficulty negotiating curbs and an increased risk of falling, as can difficulty in detecting surface irregularities in the pavement and estimating curb heights.

The FHWA handbook observes that lighting and visibility at intersections are increasingly important to pedestrians as they age (FHWA 1998):

In a survey of older pedestrians (average age of 75) involved in accidents, 63 percent reported that they failed to see the vehicle that hit them, or to see it in time to take evasive action (Sheppard and Pattinson, 1986). Knoblauch, Nitzburg, Dewar, Templer, and Pietrucha (1995) noted that difficulty seeing a vehicle against a (complex) street background may occur with vehicles of certain colors, causing them to blend in with their background. . . . Reductions in visual acuity make it more difficult for aging pedestrians to read the crossing signal (Bailey, et al. 1992).

The handbook (FHWA 1998) also notes that the physical limitations of aging pedestrians result in a greater likelihood to:

- Delay before crossing;
- Wait for longer gaps between vehicles before attempting to cross the road (Tobey, Shungman and Knoblauch 1983);
- Spend more time at the curb;
- Take longer to cross the road (Hoxie and Rubenstein 1994; Knoblauch, Nitzburg, Dewar et al. 1995); and
- Make more head movements before and during crossing (Wilson and Grayson 1980).

Given the risk that drivers may “run” an amber or red traffic signal, the handbook (FHWA 1998) observes that pedestrians and bicyclists may hesitate, waiting to see whether traffic obeys the signal. Moreover,

[b]ecause older persons have difficulty dividing attention, this scanning and decision making process requires more time than it would for a younger pedestrian. Parsonson (1992) reported that the State of Delaware has found that pedestrians do not react well to the short WALK and long flashing DON'T WALK timing pattern. They equate the flashing with a vehicle yellow period. The Florida Department

of Transportation and the city of Durham, Ontario, provide sufficient WALK time for the pedestrian to reach the middle of the street, so that the pedestrian will not turn around when the flashing DON'T WALK begins.

Turning vehicles also are a concern for aging pedestrians. The loss of peripheral vision and “useful field of view” increases an aging pedestrian’s chances of not detecting approaching and turning vehicles from the side. An analysis by Council and Zegeer (1992), also reported in the FHWA handbook, examined vehicle-pedestrian crashes and the collision types in which aging pedestrians were over-involved. The results showed aging pedestrians to be overrepresented in both right- and left-turn crashes. Young elderly persons (ages 65–74) were most likely to be struck by a vehicle turning right, whereas older elderly persons (ages 75 and older) were more likely to be struck by a left-turning vehicle (FHWA 1998).

Together, these findings from research on aging road users reinforce the overriding design principles to clarify and simplify traffic operations at intersections. By providing appropriate advance information about route choices and destinations, clearly identifying lane assignments for allowed maneuvers, and implementing conspicuous and easily comprehensible sign and signal displays for traffic control, engineers can manage workload during intersection approach and negotiation in a manner that benefits road users of all ages. Likewise, the need for intersection geometrics to convey path, direction, and speed unambiguously is universal, and such “positive guidance” is an explicit goal of the treatments presented in this chapter.

5.1.8.2 Bicyclists

Aging-related changes in capabilities may make bicycling more difficult for older riders just as it affects pedestrians. Older bicyclists face the same general concerns with decreased visual acuity, increased risk of falls, and decreased ability to judge safe gaps and avoid turning vehicles. These factors contribute to the potential difficulties older bicyclists may experience when negotiating bicycle facilities, perceiving and reacting to other users in the roadside and intersections, or perceiving and reacting to traffic control features.

Bicyclists age 50 and over pedaled an estimated 2.6 billion miles on 830 million rides in 2009, according to the *National Household Travel Survey* (U.S.DOT 2009). That number was significantly up from 1995, when people in that age group covered less than 400 million miles on 175 million rides. Bicycle riders ages 70 years to 79 years made 147 million trips in 2009; riders ages 80 years and over took 13 million trips by bike (U.S.DOT 2009).

According to a comprehensive survey released in March 2015 by PeopleForBikes (2015):

- Of Americans age 55 years and older, 19 percent rode a bike in 2014, as did 27 percent between the ages of 45 years and 54 years and 34 percent of all people over the age of two years;
- Among older Americans, 17 percent reported riding a bicycle for recreation, 7 percent reported riding as a way to get around, and 5 percent said they bicycled for both transportation and fun;
- Bicyclists ages 55 years-plus bicycle more often than any other adult group, with 42 percent riding more than 25 days a year.

Other research has found that 22 percent of the net growth in U.S. bike trips from 1995 to 2009 was by people ages 60 years to 79 years. Their bicycling quadrupled during those 14 years, the fastest growth of any demographic.

All of the above trends make it important for the designer to understand the potential for aging bicyclists to use the roadside in a project area and to address their special needs in the roadside design.

The *Handbook for Designing Roadways for the Aging Population* (FHWA 2014c) provides designers and practitioners with practical information that links aging road user performance

to highway design, operational and traffic engineering features. *Planning Complete Streets for an Aging America* (Lynott et al. 2009) and the ChORUS website (Roadway Safety Foundation et al. n.d.) are other resources available to the design practitioner. For a more in-depth discussion of these resources, see Chapter 4, “Aging Users in Multimodal Design.”

5.1.9 Freight Considerations in Roadside Design

In many urban areas, commercial vehicles face extremely challenging urban delivery conditions characterized by congested traffic and inadequate parking. At the same time, cities are increasingly looking to reduce congestion and its negative impacts by encouraging commuter shifts to non-motorized modes. However, achieving a considerable increase in bicycle mode share requires implementation of safe, often exclusive, bicycle capacities. Sparse available space, and even existing motorized vehicle capacity, are increasingly being converted for use by bicycles, resulting in even less available parking for commercial vehicles and creating an even more challenging multimodal environment at the curbside.

Freight movement is essential in urban and rural areas. Freight vehicles operate at some level on most major roadways. Freight vehicles range from single-unit box trucks to large tractor-trailer combinations. The largest vehicles are wider, have larger turning radii, and are slower to accelerate and decelerate than most other vehicles; they also have more blind spots than typical passenger vehicles. Freight vehicles also have significant mass, creating the potential for serious or fatal injuries when involved in any type of collision, especially collisions with bicyclists or pedestrians. Data from *Traffic Safety Facts: Large Trucks* (NHTSA 2015, available at <https://crashstats.nhtsa.dot.gov>) indicates that, among crashes involving large trucks, 11 percent of people killed were non-occupants such as pedestrians or bicyclists.

Conflicts between freight vehicles and bicyclists and/or pedestrians generally occur at intersections; however, mid-block conflicts also can occur, and these are typically due to loading activities. Through proper roadway design, many conflicts can be mitigated and the behavior of all users can be made more predictable.

Achieving Multimodal Networks: Applying Design Flexibility and Reducing Conflicts lists these guiding principles to reduce conflicts through better roadway design (FHWA 2016a):

- **Safety.** Through engineering, education and enforcement, roadway designers and the freight industry should consider an approach to reduce the severity and likelihood of crashes;
- **Accommodation and comfort.** Designs should provide a sense of comfort for vulnerable road users where freight vehicles are present and accommodate freight needs specific to each corridor;
- **Coherence.** The path of travel for pedestrians and bicyclists should be clearly delineated for drivers of freight vehicles to recognize;
- **Predictability.** The design should maximize predictability and reduce conflicts between vulnerable road users and freight vehicles; and
- **Context sensitivity.** The design should support community health and livability goals while maintaining and growing the economy.

5.1.9.1 Commercial Loading and Unloading

In urban and urban core contexts, many trucks typically pull to the side of the street or roadway to load and unload. This practice may result in blocking of traffic or bike lanes, and it could involve trucks crossing through a bike lane to access a loading zone. Dedicated commercial loading zones are a benefit to commercial activity, may help reduce obstruction of the bike lane, and should be provided where they will cause minimal conflict with bicycle facilities and traffic

flow. These zones can be striped and signed, or managed for off-peak deliveries (NACTO 2013). Design considerations for freight accommodation include the following:

- Consider consolidating commercial loading zones to a single location on each block to reduce potential conflicts.
- Verifying the length of typical loading vehicles that use the space when determining the length of the loading zone;
- Assessing the width needed for the loading zone (generally 8 ft. to 10 ft.);
- Providing a 5-ft. minimum access aisle between the commercial loading zone and the bike lane on roadways with on-street parking and separated bike lanes;
- Discontinuing vertical objects where an access aisle is provided;
- Using a curb ramp with a separated bike lane crosswalk, which can simplify loading and unloading activity;
- Using green-colored pavement to notify freight operators of a potential conflict with a bicyclist; and
- Locating a commercial loading zone on an adjacent block or alley where a loading zone is desired but on-street parking is not present. Lateral shifts of the separated bike lane and the sidewalk should be considered as a last resort.

5.1.9.2 Intersection Geometry

Designers should consider mountable truck aprons where turning movements by large vehicles are common. Mountable aprons discourage smaller vehicles from making turns at high speeds while still allowing trucks to turn without entering the pedestrian zone or adjacent vehicle lanes. They help reduce off-tracking risks to pedestrians with visual disabilities. Additional strategies for accommodating large vehicles at intersections include setting back stop bars and allowing large vehicles to encroach into adjacent lanes when turning.

5.1.9.3 Traffic Signal Operations

Traffic signal phases can be used to separate or provide lead-time to bicycle and pedestrian movements from conflicting freight movements. Separate signal phases can be used:

- Where a primary freight route turns and a bicycle route continues straight,
- At intersections with a high number of freight and bicycle or pedestrian crashes, and
- At intersections with separated bike lanes.

When using separate signal phases, the intersection should be designed so that tractor-trailer combinations can safely make a turn without encroaching on the bike lane, preferably with curb separation between the bike lane and the travel lane. A leading pedestrian or bicycle interval also will increase visibility and typically will reduce conflicts.

5.1.9.4 Signing

Dynamic warning signs may be used to alert freight vehicles when bicyclists are present. Dynamic signs may use various technologies to detect a bicyclist. When a bicyclist is detected, the dynamic sign illuminates to alert any potential turning vehicles to yield to the bicyclist. Any signing should comply with the MUTCD (FHWA 2009b).

5.2 Roadside Design Guidelines

This section of the Guide provides principles and guidance for the design of a roadway's roadside areas serving non-motorized users in low- and intermediate-speed environments. On roadways with traveled ways that include shoulders, non-motorized users may sometimes be

adjacent traffic. Increasing the buffer area (e.g., by providing on-street parking or a planted area) provides separation from moving traffic, and reducing speeds improves the pedestrian experience

- **Comfort.** Pedestrians choose to walk based on the influence of many factors, including distance, perceived safety and comfort, convenience and visual interest of the route.
- **Continuity.** Walking routes should be obvious and should not require pedestrians to travel out of their way unnecessarily.
- **Landscaping.** Plantings and street trees should contribute to the overall psychological and visual comfort of sidewalk users and should be designed in a manner that contributes to the safety of people.
- **Drainage.** Sidewalks should be well graded to minimize standing water.
- **Social space.** Places for standing, visiting, and sitting should be provided along sidewalks. The sidewalk area should be a place where adults and children can safely participate in public life. Sidewalks often serve the important function of providing community and civic gathering spaces, either in the form of public plazas, squares and parks, or as an extension of adjacent land uses such as outdoor dining or transit stops.
- **Place making.** Sidewalks should contribute to the character of neighborhoods and business districts.

5.2.3.3 Recommended Practice

A revised set of terminology is recommended to better communicate the purpose of each element of a pedestrian travel way. Codified in the *Walkable Urban Thoroughfares Guide* (ITE 2004) and the *Urban Street Design Guide* (NACTO 2013), these terms generally correspond to AASHTO terms. Exhibit 5-17 identifies and describes the recommended terms, and cross references them with the functionally equivalent terms used in AASHTO policy and guidance documents.

- **Design guidance.** Exhibit 5-18 provides recommended widths of sidewalk zones for low- and intermediate-speed streets in the urban contexts for local, collector and arterial roadways. These recommendations are based on AASHTO policy and guidelines, and they are modified as needed to account for three levels of non-motorized multimodal accommodation.
- **Implementation guidance.** Meandering sidewalks and paths are sometimes used when there is a desire to provide a high level of landscaping; however, they introduce additional

Exhibit 5-17. Recommended pedestrian travel way terminology.

Recommended Terminology	AASHTO Terminology	Use
Furnishings zone	Buffer Strip	Separates the pedestrian through zone from the adjacent roadway, and serves as a space to accommodate roadway and sidewalk furnishings, utilities and landscaping. In commercial areas, this space may also serve business-related activities.
Pedestrian Through Zone	Clear Travel Area	Serves through pedestrian travel along the sidewalk. This must serve basic accessibility requirements, but may expand to serve areas of high volumes of pedestrians.
Frontage Zone	Building Shy Distance	This area is adjacent to the property line and serves activities and interactions related to land use access and servicing. In commercial areas, businesses may use this space for non-transportation activities such as sidewalk cafes, portable signage or merchant displays. In less developed areas, this zone may serve for placement of utilities.

Exhibit 5-18. Recommended sidewalk zone widths by multimodal priority level and street type.

Multimodal User Priority Level	Sidewalk Zone *	Street Type		
		Local Urban Street	Urban Collector Street	Urban Arterial Street
LOW Multimodal Priority	Furnishings zone	2 ft. (0.6 m)	2–5 ft. (0.6–1.5 m)	5 ft. (1.5 m)
	Pedestrian Through Zone	4 ft. (1.2 m)*	5–8 ft. (1.5–2.4 m)	5–8 ft. (2.4 m)
	Frontage Zone	2 ft. (0.6 m)	2 ft. (0.6 m)	2 ft. (0.6 m)
MODERATE Multimodal Priority	Furnishings zone	4 ft. (1.2 m)	4–5 ft. (1.2–1.5 m)	5 ft. (1.5 m)
	Pedestrian Through Zone	5 ft. (1.5 m)	5–10 ft. (1.5–3.0 m)	10 ft. (3.0 m)
	Frontage Zone	2 ft. (0.6 m)	2 ft. (0.6 m)	2 ft. (0.6 m)
HIGH Multimodal Priority	Furnishings zone	4–6 ft. (1.2–1.8 m)	4–8 ft. (1.2–2.4 m)	6–10 ft. (1.8–3.0 m)
	Pedestrian Through Zone	5–7 ft. (1.5–2.1 m)	5–10 ft. (1.5–3.0 m)	10–12 ft. (3.0–3.6 m)
	Frontage Zone	2 ft. (0.6 m)	2 ft. (0.6 m)	2 ft. (0.6 m)

Additional width should be provided when diagonal parking is present (2.5 ft.). Where the adjacent street lacks parking or bike lanes, a minimum 6 ft. (1.8 m) width frontage zone is desirable.

* 4 ft. (1.2 m) clear travel way must be complemented with 5 ft. (1.5 m) passing zones every 200 ft. (60.0 m). This requirement may be met by the furnishing or frontage zone space.

walking distances and may introduce orientation issues for pedestrians with vision disabilities that make their use inappropriate in most settings. Meandering sidewalks should be kept within a 10-ft. (3.0-m) space parallel to the edge of the roadway width, with horizontal-curve radii no less than 300 ft. (90 m) in order to maintain a convenient walking route (AASHTO 2004b).

As much as possible, sidewalks should keep to the natural path of travel, parallel to the roadway. Ideally, they will be located in a position that naturally aligns with crosswalks at intersections. In some locations, it may be desirable for the sidewalk to curve to form a more direct route to an intersecting walkway, to preserve significant trees or to provide a greater degree of separation between the sidewalk and the road. Sidewalks immediately adjacent to high-volume pedestrian generators require special consideration. This includes sidewalks adjacent to transit stations, universities, major tourism and entertainment venues, and major destinations.

5.2.4 Bicycle Accommodations

Most bicycle accommodations along streets and roadways are provided within the traveled way. These accommodations may take the form of shared vehicle lanes, striped bicycle lanes and separated bicycle tracks. Bicycle accommodations also are addressed in Chapter 4 as a subsection under “Traveled Way Design Element Guidelines for All Users.” Roadside bicycle accommodations also can occur on sidepaths and shared-use paths. Bicycles are discouraged on pedestrian sidewalks, however, and are generally illegal to operate on sidewalks.

Facilities placed outside the traveled way can provide low-stress environments for mixed bicycling and walking activities. Well-designed shared-use paths or trails can provide direct and comfortable routes to places of employment, recreation, education and other destinations. They can enhance the efficiency of transit systems by making transit stops more accessible. They also can provide a way to engage in physical activity. Such paths also can be great places for novice and child bicyclists to test their riding skills before taking trips on urban streets.

Although sidepaths and shared-use trails that are outside the traveled way offer many positive features, their design should be approached with the same care and attention to recognized guidelines as design of bicycle facilities on roadways. Trails often are extremely popular facilities that are in high demand among pedestrian or bicycling commuters, rollerbladers, recreational bicyclists, joggers, people walking dogs, families with young children, and various other users. Trail users often have differing objectives, which can result in conflicts. The resulting mix and volume of non-motorized traffic can create dangerous conditions that should be anticipated during the design phase.

Very few trails are used exclusively by one type of user. People routinely walk on “bicycle paths” and it is safe to assume that trails will be shared by all types of users of all ages and abilities. By understanding users’ needs and designing trails to accommodate expected types and levels of use, a trail system can be designed that plays an important role in the community or region’s transportation and recreation network.

Multimodal conflicts on shared-use paths most often derive from (1) high volumes of users, (2) path users traveling at different speeds, (3) path users overtaking other users, (4) sharp curves, (5) vertical objects near the path and (6) surface defects that effectively narrow the usable width.

Increasing use of paths should be expected over time as more people become aware of them and as walking and bicycling rates grow. The design of a path should follow best practices and industry standards and consider future growth patterns. Through careful planning and design, shared-use paths can be built to accommodate current and future path volumes while reducing conflicts between users of different types and speeds.

5.2.4.1 Sidepaths and Shared-Use Paths

Most sidepaths are physically located in the roadside. The term *sidepath* implies that the bicycle facility is placed adjacent to, or beside, the traveled way. Shared-use facilities also may be located in the roadside, but they are found more often outside the roadway right-of-way.

As shown in Exhibit 5-19, shared-use paths provide off-road connections that can be used for recreation and commuting. These paths often are found along waterways, abandoned or active railroad and utility rights-of-way, limited-access highways, or within parks and open space areas.

Exhibit 5-19. Typical shared-use path.



Source: Image courtesy of FloridaBicycle.org

Along high-speed, high-volume roads, sidepaths may be an acceptable alternative to sidewalks or bike lanes, although intersection conflicts could be both less expected by users and more severe than with other treatments. As shown in Exhibit 5-20, sidepaths generally are bi-directional and located within the roadside or adjacent to the roadside. Sidepaths immediately adjacent to roadways may cross numerous intersecting roads and driveways, which can create hazards and other problems for path users. Creating safe and accessible intersections between paths and the road network is one of the most challenging and critical aspects of their design.

Shared-use paths tend to attract bicyclists with a wide range of skill levels, including young children. Even if a path has been designed primarily as a bike facility, it also will likely attract a mix of other users, including pedestrians, in-line skaters and others, depending on the path's location and access. Special care must be taken in the planning and design of such paths to provide a satisfactory experience for bicyclists and to provide safe sharing of the facility with a variety of users of differing speeds and abilities, including users with disabilities.

5.2.4.2 Current AASHTO Policy and Guidance

The Green Book (AASHTO 2011a) does not provide guidance on the design of shared-use paths or sidepaths. On the topic of bicycle facilities, it directs readers to the Bicycle Guide (AASHTO 2014b) and the Pedestrian Facilities Guide (AASHTO 2004b) for appropriate design guidance.

The Bicycle Guide (AASHTO 2014b) provides general guidance on the design of sidepaths, identifying sidepaths as being most appropriate on highways with very high motorized vehicle traffic volumes and speeds such that bicyclists might be discouraged from riding on the roadway. Safety concerns remain at intersection and driveway crossings where crossing motorists may have inadequate sight distance and may not expect to encounter crossing bicycles on the sidepath.

The Bicycle Guide provides extensive information on the potential safety concerns with sidepath operation and expresses caution about potential operational challenges with their use. Specific conflicts that may apply to some sidepath designs include issues with blockage of the sidepath by motorized vehicles stopped at intersections, concerns about visibility of sidepath users at driveways and intersections, a lack of awareness by motorists of bicyclists approaching from the right, and issues with transitions onto the roadway where the sidepath ends, among others. The Bicycle Guide notes that, although paths in independent rights-of-way are their preferred use, sidepaths may typically be considered where one or more of the following conditions exist (AASHTO 2014b):

- The adjacent roadway has relatively high-volume and high-speed motorized vehicle traffic that might discourage many bicyclists from riding on the roadway, potentially increasing sidewalk riding, and no practical alternatives exist for either improving the roadway or accommodating bicyclists on nearby parallel streets;

Exhibit 5-20. Typical sidepath.



Source: Image courtesy of TrailLink

- The sidepath is used for a short distance to provide continuity between sections of path in independent rights-of-way, or to connect local streets that are used as bicycle routes;
- The sidepath can be built with few roadway and driveway crossings; and
- The sidepath can terminate at each end onto a street that accommodates bicyclists, onto another path, or at another location that is otherwise bicycle compatible.

The preferred width of sidepath facilities is 12 ft. This width is needed to enable a bicyclist to pass another path user going the same direction, while another path user is approaching from the opposite direction. The preferred minimum width is 10 ft., and the absolute minimum width is 8 ft. This width should be considered only in constrained conditions for short distances (AASHTO 2014b, Section 5.2.1). Exhibit 5-21 summarizes recommended sidepath widths.

Separation between the sidepath and roadway requires a minimum of 5 ft. of unpaved surface. Where such width is not available, a barrier may be used between the sidepath and the roadway.

Graded shoulders should be provided on each side of the path. A lateral offset of 3 ft. should be provided to signs or other fixed objects.

The Bicycle Guide concludes that one-way paths on both sides of the street, which may operate similarly to directional separated bike lanes, “can reduce some of the concerns associated with two-way sidepaths at driveways and intersections” (AASHTO 2014b).

5.2.4.3 Sidepath Principles and Considerations for All Users

Attributes of well-designed sidepaths include:

- **Adequate width.** Sidepaths should be designed to allow two people to ride side-by-side and/or pass other users. Eleven-ft.-wide (3.4-m-wide) pathways are needed to enable a bicyclist to pass another path user going in the same direction, at the same time a path user is approaching from the opposite direction (AASHTO 2014b).
- **Visibility at driveways and crossings.** Clear sight lines should be provided between the roadway and the sidepath in advance of driveways and intersections.
- **User separation.** Where high volumes of multiple user types exist, separation between bicyclists and pedestrians is desired.

5.2.4.4 Recommended Practice

- **Design guidance.** Exhibit 5-22 provides recommended widths of sidepaths for low- and intermediate-speed streets in urban contexts in response to three levels of non-motorized multimodal accommodation.

Sidepath width affects user comfort and path capacity. As user volume or mix of modes increases, increased path width is necessary to maintain comfort and functionality.

Exhibit 5-21. AASHTO-recommended sidepath widths.

Separated Bike Lane Area	Minimum Width	Preferred Minimum Width
Roadway Separation	5 ft. (1.5 m) *	5 ft. (1.5 m)
Clear Travel Area	10 ft. (3.0 m)**	12 ft. (3.6 m)
Graded Shoulder	1 ft. (0.3 m)	2 ft. (0.6 m)

* Roadway separation may be reduced if a physical barrier is provided.

** An absolute minimum width of 8 ft (2.4 m) may be considered in constrained conditions.

Source: AASHTO (2014b)

Exhibit 5-22. Recommended sidepath attribute widths by multimodal priority level.

Multimodal User Priority Level	Sidepath Attribute	Recommended Widths
LOW Multimodal Priority	Roadway Separation	5 ft. (1.5 m)
	Clear Travel Area	10 ft. (3.6 m)
	Graded Shoulder	2 ft. (0.6 m)
MODERATE Multimodal Priority	Roadway Separation	5 ft. (1.5 m)
	Clear Travel Area	11–12 ft. (3.4–3.6 m)
	Graded Shoulder	2 ft. (0.6 m)
HIGH Multimodal Priority	Roadway Separation	5–8 ft. (1.5–2.4 m) or greater
	Clear Travel Area	11 ft. (3.4 m)–20 ft (6.0 m) *
	Graded Shoulder	2 ft. (0.6 m)

* At widths beyond 15 ft., separated paths may be provided for bicyclists and pedestrians.

Exhibit 5-23 identifies the preferred pathway width in response to volume and user mix, as needed to achieve LOS “B,” as calculated by the FHWA *Shared Use Path Level of Use Calculator* (FHWA 2006c).

Sidepaths designed to serve extremely heavy user volumes should be configured with separated paths for separate users. Accomplishing this requires a minimum width of 15 ft. (4.6 m), with 10 ft. (3.0 m) provided for two-way wheeled traffic and 5 ft. (1.5 m) provided for pedestrians (AASHTO 2014b). A sidepath with separated treads may function similarly to a two-way separated bike lane (see “Separated Bike Lanes” in Chapter 4).

- **Implementation guidance.** Sidepaths have operational and safety concerns at driveways and intersections. The design of crossings should promote awareness of conflict points with crossing and turning vehicles and should facilitate proper yielding of motorists to bicyclists and pedestrians.

In some design settings, wrong-way cyclists may be a concern. The AASHTO Bicycle Guide (AASHTO 2014b) offers additional guidance on this subject.

Provision of a shared-use path adjacent to a road is not a substitute for the provision of on-road accommodation (e.g., paved shoulders or bike lanes). In some locations, shared-use paths may be considered in addition to on-road bicycle facilities (AASHTO 2014b).

Exhibit 5-23. Pathway volume and user mix.

Volume and User Mix	Preferred Pathway Width
Medium user volume (less than 50 users in one direction per hour), low user mix (75% bikes, 25% pedestrians)	8–10 ft. (2.4–3.0 m)
Medium user volume (less than 50 users in one direction per hour), heavy user mix (50% bikes, 50% pedestrians)	10–12 ft. (3.0–3.6 m)
High user volume (150 or more users in one direction per hour), low user mix (75% bikes, 25% pedestrians)	12–14 ft. (3.6–4.2 m)

Source: Adapted from FHWA (2006c)

Where a sidepath terminates, it may be necessary for path users to transition to a facility on the opposite side of the road. Designs should consider the desire for natural directional flows and the potential for conflicts with adjacent traffic.

Small Town and Rural Multimodal Networks (FHWA 2016e) is a resource intended for transportation practitioners in small towns and rural communities. It applies existing national design guidelines in a rural setting and highlights small-town and rural case studies. It addresses challenges specific to rural areas, recognizing how many rural roadways are operating today and focusing on opportunities to make incremental improvements despite the geographic, fiscal and other challenges faced by many rural communities. This FHWA document provides information on maintaining accessibility and MUTCD (FHWA 2009b) compliance while encouraging innovation. For example, it highlights two innovative facility types: yield roadways and advisory shoulders (dashed bicycle lanes). The document notes that, as of 2016, an approved Request to Experiment is required to implement advisory shoulders.

5.2.5 Transit Service Accommodations

Public transit helps cities provide accessible and affordable transportation, improve local air quality, increase transportation capacity without expanding roadways, and encourage compact mixed-use development. Roadside design practices include the accommodation of transit service facilities, providing enhanced facilities in locations that prioritize multimodal travel (e.g., in central business districts and other dense, high-traffic commercial areas). Designers must consider the needs of transit riders when designing curbside stops to improve service efficiency and performance while balancing the interests of other roadway users. Design considerations also include the street classification, site context and level of transit ridership.

This section addresses bus transit accommodations only; rail transit accommodations present a broader and more complex range of challenges. The *Guide for Geometric Design of Transit Facilities on Highways and Streets* (AASHTO 2014a) and the *Transit Street Design Guide* (NACTO 2016) should be consulted for designing transit accommodations other than bus accommodations.

5.2.5.1 Current AASHTO Policy and Guidance

The Green Book (AASHTO 2011a) states that, when land use patterns generate demand for passenger car traffic, there is likewise potential demand for public transportation. When a street is served by public transit, roadside accommodations must be provided to support that service as well as devoting the appropriate space connecting sidewalks to transit stops. Transit stops can be designed either as an in-line facility or with a pullout clear of the lanes for through traffic.

The Green Book recommends the use of pullouts whenever sufficient right-of-way is available (or by restricting on-street parking) to reduce interference between buses and other motorized vehicles, as long as the pullout (turnout) is well designed for the driver to enter and then maneuver back into traffic (AASHTO 2011a). A two-bus-length pullout should be, at minimum, 130–180 ft. (40–55 m) long, depending on whether the stop is located before or after an intersection, or whether it is located mid-block. Mid-block locations require the most space while far-side stops require the least. The Green Book recommends the use of longer pullouts to speed up bus maneuvers, and reduce interference with through traffic (AASHTO 2011a).

The Pedestrian Facilities Guide (AASHTO 2004b) recognizes the need for transit stops to provide a designated space for loading and unloading passengers. Stops can consist of a simple sign and a designated space at the curb, pullout area or shoulder. Stops also can include enhancements to improve passenger experience (e.g., shelters, benches, real-time arrival signs, trash receptacles, lighting and other furnishings). Shelters must have a minimum clear floor area of

2.5 ft. (0.8 m) by 4 ft. (1.2 m) entirely within the perimeter of the shelter, with pedestrian access to the boarding area (AASHTO 2004b).

The Pedestrian Facilities Guide (AASHTO 2004b) requires newly built transit stops to include an 8 ft. (2.4 m) by 5 ft. (1.5 m) landing pad to provide accessibility for all users and compliance with ADAAG 10.2.1 (U.S. Access Board 2002). The Pedestrian Facilities Guide also recommends a continuous 8 ft. (2.4 m) pad or sidewalk for the entire length of the transit stop, or at minimum between the front and rear doors of the bus, without interference from utility poles, fire hydrants or other street furniture to impede access to transit stops and loading areas (AASHTO 2004b).

The *Guide for Geometric Design of Transit Facilities on Highways and Streets* (AASHTO 2014a) recommends that communities weigh the trade-offs between improving the pedestrian experience and accommodating transit vehicles and other general traffic.

The AASHTO *Guide for Geometric Design of Transit Facilities on Highways and Streets* provides the following guidance on the selection of transit stop treatments (AASHTO 2014a).

- Curbside stops are used on all types of roads, where parking can be either permitted or prohibited;
- *Bus bays* (pullouts) are appropriate along roadways where the curb lanes are used by moving traffic and vehicle speeds are higher (over 40 mph);
- *Bus bulbs* (transit stops in curb extensions) are appropriate in urban environments that allow parking at all times, have frequent transit service and high levels of pedestrian activity, and generally experience lower traffic volumes and lower vehicle speeds (e.g., under 40 mph);
- Bus bulb curb extensions should be a minimum of 6 ft. (1.8 m) wide and leave an offset of 2 ft. (0.6 m) between the bulb and the edge of the travel lane, assuming an 8-ft. parking space; and
- Bus bulb curb extensions should be long enough to allow for simultaneous boarding of as many buses as required given peak transit frequencies.
- Bus bulb curb extensions should be a minimum of 6 ft. (1.8 m) wide and leave an offset of 2 ft. (0.6 m) between the bulb and the edge of the travel lane, assuming an 8 ft. parking space; they also should be long enough to allow for simultaneous boarding of as many buses as required given peak transit frequencies (AASHTO 2014a).

Bus pullouts are used mainly on higher-volume, higher-speed suburban roads to enable buses to serve the stop without impeding traffic. The pullout creates separation from moving traffic for passenger boarding and can be appropriate for buses with long dwell times or during a layover; however, difficulty when reentering the flow of traffic from a pullout can lead to increased transit delay for the buses, especially when traffic exceeds 1,000 vehicles per hour per lane.

The AASHTO transit guide recommends building pullouts where right-of-way width is adequate without affecting sidewalk functionality. Additional considerations to consider are where traffic in the curb lane is between 250–500 vehicles during the peak hour, when speeds are higher than 40 mph, where bus frequency is between 10–15 vehicles in each direction during the peak hour, and where transit passenger volumes exceed 20 to 40 boardings per hour each way (AASHTO 2014a).

Bus platforms should be at least 8 ft. (2.4 m) wide, with 10 ft. (3 m) provided if there are no adjacent sidewalks. In constrained conditions (e.g., when curb to building distance is less than 10 ft. [3 m]), a reduced pad width may be needed. The platform length should be a minimum of 25 ft. (7.5 m); a longer length may be necessary to cover all doors given the types and number of buses that serve the stop at any given time. Specific stop dimensions will depend on the bus type in the transit system, the need for and dimensions of passenger shelters, and well as the number of waiting passengers (AASHTO 2014a).

5.2.5.2 Additional Guidance

The *Transit Street Design Guide* (NACTO 2016) details how reliable public transportation depends on a commitment to transit at every level of design, and provides guidance for the development of transit facilities on city streets and the design of city streets to prioritize transit, improve transit service quality and support other goals related to transit. This guide was developed on the basis of other design guidance, city case studies, best practices in urban environments, research and evaluation of existing designs, and professional consensus. The specific guidance, designs and elements included in the guide are based on North American street design practice.

5.2.5.3 Transit Service Accommodation: Principles and Considerations for All Users

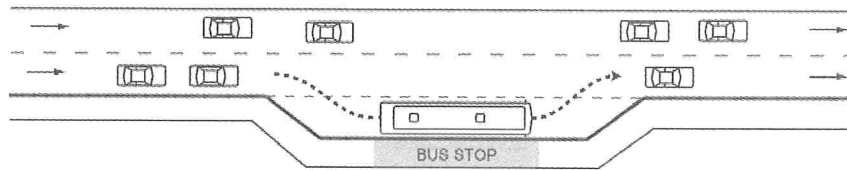
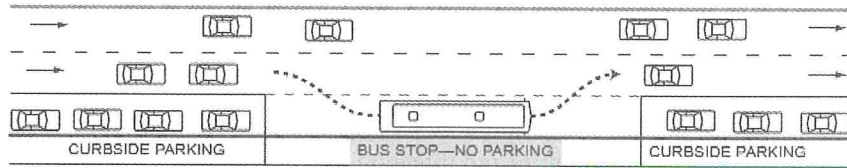
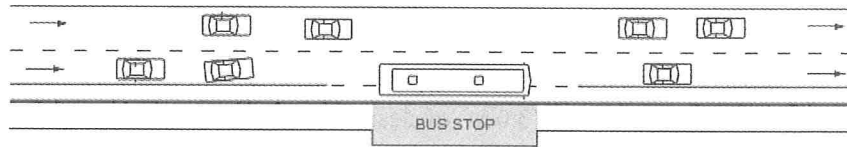
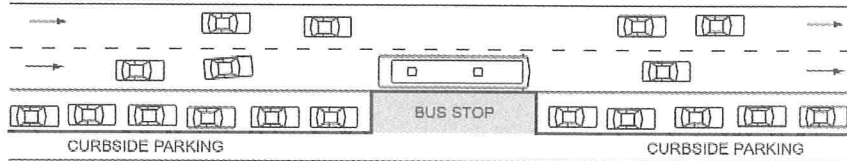
- **Accessibility.** Transit accommodations should be accessible to persons using mobility devices such as wheelchairs. Transit stops and stations should be fully accessible in accordance with the provisions of the most current ADA guidelines (U.S. Access Board 2011). Guidelines cover pathway width, space for wheelchairs, grades, treatment of obstructions, and placement and design of signs. A goal should be to exceed the minimum standard to provide adequate accommodations and minimize impact of site design conditions.
- **Multimodal access.** Transit stops and stations should be designed to integrate with a connected network of bikeways and walkways. Based on the needs at the transit stop and the land use in the area of the stop or station, short- and long-term bicycle storage such as bicycle racks or lockers should be provided at stops and stations so that users can continue their trips on public transportation.
- **Integration with land uses.** In the urban street environment, transit service should be closely coordinated with the surrounding developments. Each should support the other in making communities more livable and in enhancing transit ridership (AASHTO 2014a).
- **Priority in mixed traffic.** The selection of pullout (turnout) stops or in-lane stops should be based on service levels of the transit system on that route, as well as overall traffic operations on the route. A pullout allows motorists to pass the stopped bus, but may cause a significant transit delay when buses have to reenter the travel lane. In-lane curbside or curb extension stops reduces transit delays compared to pullout stops and may provide more space for amenities, stormwater treatments, and sidewalk space.

5.2.5.4 Recommended Practice

Four general types of transit stop configurations exist, from which a selection is made in response to the available right-of-way, cross-section configuration and desired degree of multimodal accommodation (see Exhibit 5-24). These configurations are:

- **Auxiliary bus turnout stops.** Also called *bus bays* or (as in this Guide) *bus pullouts*, this configuration establishes an auxiliary bus loading lane outside of the adjacent travel lane;
- **Curbside bus pullout stops.** Used on streets that have on-street parking or shoulders, this configuration allows the bus to pull directly to the curb alongside the adjacent travel lane;
- **In-lane curb extension bus stops.** On streets that have on-street parking or shoulders, the transit vehicle may stop in the travel lane by a transit stop that is located within a curb extension; and
- **In-lane curbside bus stops.** On streets without on-street parking, the transit vehicle may stop in the travel lane alongside marked transit stops located behind the curb of the sidewalk.

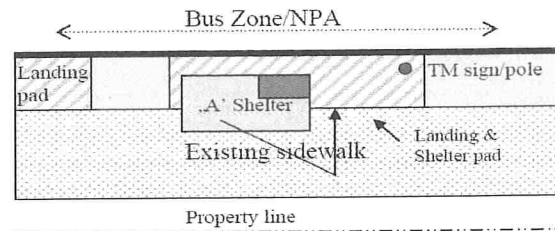
Exhibit 5-25 identifies recommended bus stop configurations for low- and intermediate-speed streets in response to multimodal priority and the presence of on-street parking.

Exhibit 5-24. Bus stop configuration types.**Auxiliary Bus Stop Turnout****Curbside Bus Stop Turnout****In-Lane Curbside Bus Stop****In-Lane Curb Extension Bus Stop**

Source: Adapted from content in *TCRP Report 100* (Kittelson & Associates, et al. 2003)

Exhibit 5-25. Recommended transit stop configuration by multimodal priority level and presence of on-street parking.

Multimodal User Priority Level	Parking Configuration	Recommended Bus Stop Configuration
LOW Multimodal Priority	No Parking	Auxiliary turnout stop
	On-Street Parking	Curbside turnout stop
MODERATE Multimodal Priority	No Parking	In-lane curbside stop
	On-Street Parking	Curbside turnout stop or curb extension stop
HIGH Multimodal Priority	No Parking	In-lane curbside stop
	On-Street Parking	Curb extension stop

Exhibit 5-26. Transit stop configuration with furnishings zone.

Source: Excerpt from Diagram 3: Bus stop design: sidewalks with furnishings zones (Basic), in TriMet *Bus Stops Guidelines* (2010, 18), used by permission

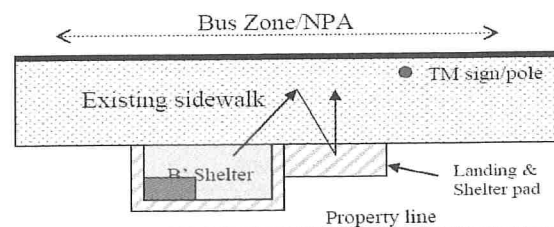
5.2.5.5 Transit Platform Design

Transit platforms should be designed to accommodate waiting transit passengers, include transit shelter amenities and integrate well into adjacent sidewalks.

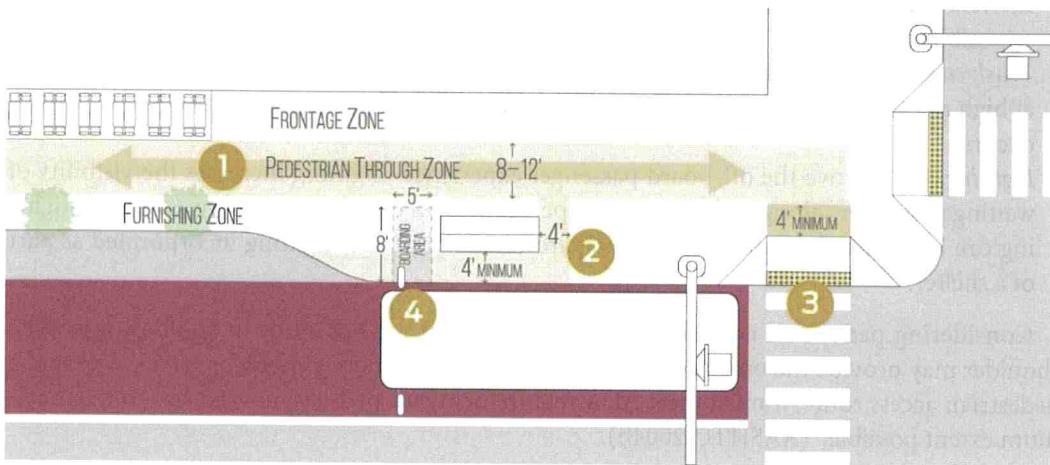
Transit stops must include easily identifiable signage and a paved area that is accessible to all passengers. Platforms should be at least 35 ft. (10.6 m) long to accommodate a single 40-ft. bus, or long enough to cover all doors of each bus that is expected to simultaneously serve the stop during peak hours. An additional length of 5–10 ft. (1.5–3.0 m) is needed between each additional transit vehicle expected to dwell at the platform. In addition, there should be a minimum of 10 ft. (3.0 m) of clear distance between the platform and the nearest crosswalk or curb return.

Exhibit 5-26 depicts a bus transit stop platform that incorporates an available furnishings zone for transit boarding and alighting. Exhibit 5-27 shows an example of a bus transit platform incorporated as part of a narrow sidewalk with no furnishings zone. Exhibit 5-28 shows a curb extension bus stop and illustrates a desirable approach for integrating an urban bus stop with the roadside.

Transit stop platforms must provide ADA-required access to accommodate all passengers. A pedestrian access route that is at minimum 4-ft. (1.2 m) wide and clear of obstructions is necessary to connect the transit shelter to the loading area, street, and sidewalk. When transit facilities are adjacent to sidewalks, a sidewalk pedestrian through zone of 8 ft. to 12 ft. (2.4–3.6 m) or greater should be provided. Where possible, pinch-points in the pedestrian through zone should be avoided; however, a minimum of 6 ft. (1.8 m) of clear sidewalk space is suitable for constrained conditions.

Exhibit 5-27. Transit stop configuration without furnishings zone.

Source: Excerpt from Diagram 4: Bus stop design: sidewalks without furnishings zones (Basic), in TriMet *Bus Stops Guidelines* (2010, 19), used by permission

Exhibit 5-28. Preferred sidewalk and transit stop dimensions.

Source: NACTO (2016)

All transit stops should incorporate the following elements (AASHTO 2004b):

- A *pole and transit stop sign* to identify the stop. Poles should be placed 2.5 ft. (0.75 m) from the curb.
- An *accessible landing pad* to provide wheelchair lift access. This clear, level landing area must be a minimum of 5 ft. (1.5 m) by 8 ft. (2.4 m). If the stop is located in an area with a furnishings zone, the landing pad can be incorporated within that area while maintaining a pedestrian through zone on the sidewalk (see Exhibit 5-27). If the stop is in an area without a furnishings zone and sidewalks are narrower than 8 ft. (2.4 m), the landing pad can protrude behind the sidewalk toward the property line (see Exhibit 5-28).
- A *bus zone* (when necessary). For bus stops to be accessible, a transit vehicle must have a clear path to the stop area.

Where on-street parking is available, a no-parking area should be implemented to allow for curb access. Depending on each stop's near-side, far-side, or mid-block location, the length of the no-parking area may range from 90 ft. to 150 ft. (27.0–45.0 m). The zone length should be increased if more than one bus is expected to use the stop at one time (AASHTO 2014a).

At auxiliary pullout stops, a deceleration lane or taper should permit easy entrance for the bus to the bus loading area. The taper should be at an angle (minimum of 5:1) that is flat enough to encourage the bus operator to pull completely clear of the through lane before stopping. A merging lane enables buses to reenter the general travel lanes, tapered at a maximum of 3:1 (AASHTO 2014a).

Depending on the available space and current or expected ridership, designs for transit stops may include the following elements (AASHTO 2014a):

- A *rear landing pad*, integrated into the transit platform to provide accessibility for alighting passengers, in addition to an ADA-accessible landing area to access the front door. The landing area should be clear of obstacles and with a minimum dimension of 4 ft. × 6 ft. (1.2 m × 1.8 m).
- A *transit shelter*, to provide seating and protection from inclement weather. Shelters are recommended at stops with higher ridership or where there is a higher expectation of senior citizen ridership or heavier use of wheelchair lifts. Shelters will normally have a minimum accessible clear floor area of 2.5 ft. × 4 ft. (0.8 m × 1.2 m) entirely within the perimeter of the shelter and a clear pathway from the accessible waiting area inside the shelter to the accessible landing pad.

- *Seating*, to improve the off-board passenger experience. Seating can be incorporated into shelters or installed independently. Seating placement should not compromise safety or accessibility.
- *Trash cans*, to improve the off-board passenger experience. Trash cans are most appropriate at high ridership stops (e.g., transfer locations) or where a high volume of pedestrian activity occurs.
- *Lighting*, to improve the off-board passenger experience. Lighting increases the visibility of waiting passengers along with passengers' perceptions of comfort and safety. Overhead lighting can be oriented toward the boarding area, with additional lighting incorporated as part of a shelter.

Considering pedestrian accessibility also is important for bus stops in rural settings. The shoulder may provide the only access to the bus stop, and "where a shoulder serves as part of a pedestrian access route, it must meet ADA requirements for pedestrian walkways to the maximum extent possible" (AASHTO 2004b).

- **Implementation guidance.** Providing route information and wayfinding tools at stops improves the passenger experience by making the transit system easier to use and reducing travel uncertainty, especially if real-time arrivals are provided. The information provided can include details on the surrounding neighborhood and nearby destinations.

As with sidewalks, transit stops can incorporate green infrastructure to improve water quality, reduce stormwater runoff, and reduce impact on water treatment systems to provide an inviting environment for transit users. Green infrastructure is suitable at bus bulbs where extra sidewalk space is available, and can help calm traffic, reduce crossing distance and improve the aesthetics of the stop environment.

Bike parking that includes short-term racks or longer-term storage can help improve intermodal connectivity to transit, which boosts ridership and reduces reliance on on-bus bicycle racks. Improving bicycle parking expands transit reach that addresses last mile travel to and from stops, and improves access to adjacent destinations that are beyond walking distance.

The *Pedestrian Safety Guide for Transit Agencies* (FHWA 2013c) provides an extensive discussion of design and operational features that roadway designers can consider to increase the safety of pedestrians accessing transit. Guidance from this resource includes the following:

- The design of paths, sidewalks and transit stops contributes to a passenger's experience and perception of safety on the transit system;
- Well-connected sidewalks should be installed in all areas with regular transit service so that transit patrons will not be forced to walk in the street while traveling to or from a stop or station; and
- Roadway crossings should be made safer with an appropriate combination of facilities, such as marked crosswalks, median crossing islands, warning signs, and pedestrian signals; and
- Effective pedestrian design should account for the needs of all potential users, including those with physical or mental limitations.

When applied appropriately, *universal design* concepts ensure that the built environment can be shared by all people, thus eliminating the need for specialized design. The ADAAG (U.S. Access Board 2002) describes the minimum designs for providing accessibility for all pedestrians, but FHWA's *Pedestrian Safety Guide* notes that the ADAAG is just the starting point for ensuring that universal design is applied. The following sources are recommended for best practices to accommodate all pedestrians (FHWA 2013c):

- *Designing Sidewalks and Trails for Access, Part I, A Review of Existing Guidelines* (FHWA 2001c);
- *Designing Sidewalks and Trails for Access Part II, Best Practices Guide* (FHWA 2001d);
- *and*
- *Guide for the Planning, Design, and Operation of Pedestrian Facilities* (AASHTO 2004b).

5.2.5.6 Sidewalk Design

Creating safer places for pedestrians to travel along roadways can encourage more people to use transit systems. It is critical to ensure that sidewalks and other pedestrian pathways along roadways have appropriate width, surface, separation from motorized vehicle traffic, lighting and signage.

- **Sidewalk width.** Sidewalks should be wide enough to accommodate the expected levels of pedestrian traffic. Narrow sidewalks that cannot accommodate the volume of foot traffic may encourage pedestrians to walk in the roadway or take alternate routes, increasing the potential for conflict with motorized vehicles. It is desirable to provide a sidewalk clear width (i.e., lateral space available for pedestrian travel for the length of a corridor) at least wide enough to accommodate two people walking side-by-side.

ADA guidelines specify a minimum clear width of 5 ft. to accommodate users in wheelchairs (36 CFR Part 1190). In areas with high pedestrian volumes (often areas near transit stops and stations), sidewalks may need to be wider to accommodate pedestrians. Street furniture (e.g., trash cans, newspaper racks), utilities, and street trees present obstacles to pedestrians and reduce the sidewalk clear width. Obstacles should be placed outside of the normal pedestrian travel path, ideally in the buffer zone (i.e., between the street and the sidewalk) to ensure that the sidewalk provides direct pedestrian paths.

- **Surface.** The full clear width of a sidewalk should be paved with a smooth, stable and slip-resistant material to accommodate wheelchairs, bicycles and strollers. The sidewalk should be clear of obstructions, including overhanging branches, utility poles and signs.
- **Buffer.** For the safety and comfort of pedestrians, a buffer area between the sidewalk and roadway is often desirable (i.e., sidewalks should not be located against the curb, directly adjacent to the lanes of moving traffic). Some form of buffer should be included to protect pedestrians from noise, wind and vehicle splash caused by passing vehicles and errant vehicles. Landscaping, such as a simple grass strip, shrubs or trees, can be used to provide a buffer. A tree-lined buffer has the added benefit of improving roadway aesthetics, providing shade and improving pedestrians' perceptions of safety with respect to motorized vehicle traffic. On-street parking can also serve as a buffer between moving vehicles and pedestrians while simultaneously slowing vehicular traffic.
- **Other amenities.** Other sidewalk design considerations and amenities include:
 - *Driveway crossing design.* Crossing design is important for providing safe, accessible sidewalks. Grade changes between the sidewalk and the driveway should be minimized, and corner radii should be made as small as possible to encourage drivers to turn slowly and yield to pedestrians.
 - *Lighting.* Ample, consistent and uninterrupted lighting helps ensure the safety and security of all pedestrians, including customers accessing transit. *A Resident's Guide for Creating Safe and Walkable Communities* includes more information about lighting requirements for pedestrian facilities (FHWA 2015a).
 - *Directional signage.* Installed around heavily used transit stops, directional signage enables passengers to find their way to local points of interest. Signage should be scaled for pedestrians and should be designed to be understood by all pedestrians, including those with visual impairments and limited English proficiency.
 - *Visual obstructions.* Large shrubs, utility boxes or other visual obstructions that impair drivers' ability to see pedestrians should be avoided.

5.2.5.7 Roadway Crossings

Pedestrians and bicyclists often must cross roadways when traveling to and from transit stops, and these crossings should be made as safe as possible. Roadways and pathways should be designed to facilitate safe interactions between bicycles and cars, trucks, transit vehicles, and pedestrians. Marked crosswalks are commonly used to identify preferred roadway crossing

locations. In many cases, however—particularly on multilane roads with high speeds and high traffic volumes—marked crosswalks alone are not sufficient to assure the safety of pedestrians or bicyclists. FHWA guidelines state that “in most cases, marked crosswalks are best used in combination with other treatments (e.g., curb extensions, raised crossing islands, traffic signals, roadway narrowing, enhanced overhead lighting, traffic calming measures etc.)” (FHWA 2015a).

Detailed engineering analysis will help to determine the appropriate combination of treatments for a pedestrian crossing. When implemented with education and enforcement programs, infrastructure improvements can make crossings safer and more convenient for transit customers and can help reduce pedestrian crashes.

One critical aspect of pedestrian crossing safety is the sight distance between pedestrians and drivers approaching a crossing. Adequate sight distance should be provided for drivers to see pedestrians entering a crosswalk and stop their vehicles. Sight distance can be limited by hills, curves, buildings, parked cars, landscaping, trees and other objects. At roadside transit stops, poorly placed shelters or non-transparent shelters can limit the ability of drivers to see pedestrians at or near the stop. In addition, transit vehicles servicing passengers at stops can block the sight lines between pedestrians crossing the roadway and other approaching drivers. Crossings placed near bus stops in low-density and rural areas may be of particular concern for two reasons: (1) minimum geometric standards may not be met or maintained consistently, and (2) pedestrians gather less frequently, meaning that motorists may be less likely to expect them. Many of the roadway crossing treatments presented in this section can help address sight distance issues.

Possible design elements for improved pedestrian roadway crossings include:

- Marked crosswalks,
- Median islands,
- Curb extensions,
- Reduced curb radii,
- Narrowed or reduced motorized vehicle travel lanes,
- Warning signs and signals for pedestrians and bicyclists (crossing on foot), and
- Grade-separated crossings.

In some areas, pedestrians or bicyclists also may need to cross railroad or light rail tracks to access a transit station or stop. The design of these crossings is critical because pedestrian/train or bicycle/train collisions typically result in severe or fatal injuries.

Although most current standards and requirements for railroad at-grade warning systems are tailored to motorized vehicle traffic, the *Railroad-Highway Grade Crossing Handbook* (FHWA 2007b) provides guidance about pedestrian crossings. Additional guidance is provided in:

- Part 8 and Part 10 of the MUTCD (FHWA 2009b),
- Volume 1, Section 3 in the American Railway Engineering and Maintenance of Way Association (AREMA) *Communications and Signals Manual*, available online (AREMA n.d.), and
- CFR 49 Part 234.

Railroads shall provide a minimum of 20 seconds of warning time, with the active warning devices (e.g., bells, flashing lights, barricades) fully deployed 5 seconds before the arrival of a train or transit vehicle. This gives a pedestrian a minimum of 15 seconds to complete crossing the tracks. Longer crossings may necessitate that additional warning time be built into the train-detection system. In addition to time, the type of surface material used at the rail crossing must be designed in accordance with the ADAAG (U.S. Access Board 2002).

At-grade crossings with multiple tracks can present additional dangers. Pedestrians or bicyclists may assume that a warning has been deployed for a train that is currently stopped on one

of the tracks while an unperceived second train is approaching on another track. For these locations, separate warnings may be necessary to provide adequate alerts to pedestrians or bicyclists.

Safety treatments that can be used at rail locations include:

- Traditional gate/flasher/bell assemblies,
- Active or passive warnings,
- Fencing,
- Grade-separated crossings, and
- Crossing surveillance, combined with educational outreach and enforcement efforts.

When considering what, if any, warning system is to be deployed, designers are advised to make a thorough review of the environment around the crossing. This review includes evaluating the frequency of rail service and number of tracks that are present. The assessment also should include land uses and frequently used pedestrian or bicycle pathways near the railroad track. Railroads near schools, playgrounds, hospitals, retail centers and other major pedestrian generators may have a much greater need for safety treatments than a railroad track in a rural setting. Designers also must be aware of the different standards and approaches applied to at-grade crossings of light rail and streetcar tracks, which often have no gates or warning devices.

In areas with expected bicycle traffic, bicycle-specific facilities (e.g., on-street bicycle lanes, climbing lanes, or shared lane pavement markings) should be installed. Any off-street facilities provided for both pedestrians and bicyclists should provide a safe area for bicyclists that does not impede or endanger pedestrians. AASHTO's Bicycle Guide (2014b) should be consulted during planning, design, and construction projects to ensure that appropriate bicycle facilities are provided.

As noted in the Bicycle Guide, railroad tracks that cross roads or bicycle use paths on a diagonal can cause steering difficulties for bicyclists. Depending on the pavement condition, evenness of elevations, crossing angle and width/depth of the flangeway opening, a bicycle wheel can be diverted from its intended path, resulting in a crash and/or damage to the wheel or tire. The AASHTO Bicycle Guide provides detailed recommendations that address these potential issues (AASHTO 2014b).

5.2.6 Landscaping and Stormwater Management

5.2.6.1 Landscaping

Roadside landscaping is typically provided in many urban core, urban, suburban and rural town contexts. Although landscaping is not a specific accommodation for pedestrians or bicycles, in contexts with pedestrian and bicycle activity landscaping often is considered an important amenity. Allocating roadside space to landscaping can help improve the aesthetics of the streetscape, provide a buffer between the roadway and sidewalk that improves pedestrian comfort, and facilitate stormwater management through bioretention features such as planters and swales.

Landscaping typically occupies the furnishings zone of the sidewalk corridor. It is most feasible when there is sufficient space to provide landscaping in addition to an adequately wide clear pedestrian through zone.

5.2.6.2 Current AASHTO Policy and Guidance

The Green Book recommends landscaping as a way to improve roadside aesthetics, lower construction and maintenance (and costs), and “create interest, usefulness, and beauty for the pleasure and satisfaction of the traveling public without increasing the potential crash severity for motorists who unintentionally run off the roadway” (AASHTO 2011a). The Green Book

recommends landscape development that retains the highway's character and environment while maintaining a sufficiently wide clear path that takes into account pedestrians with disabilities.

Landscaping features are most suitable in the "border area," which is provisioned for the sidewalk, for snow storage, and for the placement of underground and above-ground utilities. At intersections, any landscaping in the clear sight triangle should be maintained no higher than 2 ft. above the roadway grade so as not to impede visibility (AASHTO 2011a).

The Pedestrian Facilities Guide recommends plantings and street trees as one of the fundamental attributes to good roadway design that accommodates pedestrians (AASHTO 2004b). These treatments "contribute the overall psychological and visual comfort of sidewalk users" and help encourage walking behaviors by separating the pedestrian travel way and moving traffic (AASHTO 2004b). Furnishings zone plantings help protect pedestrians from roadside spray during inclement weather, provide an increased sense of security, and can direct pedestrians—especially those with vision impairments—to appropriate crossing locations and increase awareness for approaching motorists.

Street trees typically are used as a buffer between the roadway and sidewalk to help improve the visual quality of the street and to help calm traffic while providing shade to pedestrians. Street trees with large canopies should have their branches regularly trimmed so that they are at least 7 ft. (2.1 m) high above the sidewalk. Trees with large trunks or with root patterns that may eventually cause the sidewalk to heave and shift vertically, or that may damage nearby structures, are generally to be avoided. Tree well sizes vary based on the width of the sidewalk and the type of tree used for planting, but tree wells should be placed outside of the pedestrian clear zone and flush with the sidewalk surface. Tree wells also should have drainage grate gaps that are narrow enough to prevent stroller wheels, wheelchairs, canes or high-heeled shoes from becoming lodged in the grate.

AASHTO (2004b) recommends 6 ft. (1.8 m) of width for a planting strip if there is no on-street parking or bike lane. The desirable landscape buffer width is 5 ft. to 6 ft. (1.5–1.8 m) for arterials and 2 ft. to 4 ft. (0.6–1.2 m) for local or collector streets.

Trees, planting strips or boxes should be carefully designed to not obscure visibility at crosswalk locations or negatively impact perceived security, which can discourage pedestrian activity at night. Moreover, the *Roadside Design Guide* (AASHTO 2011b) also recommends designing plantings and trees to maintain a clear vision space from 3 ft. to 10 ft. (1.0–3.0 m) above the roadway grade to facilitate proper sight distance. Placement of trees also should consider where they will not interfere with overhead utilities or car doors, and provide sufficient buffer between trees and other roadside furniture. Frequent maintenance may be needed to prevent plantings and shrubs from encroaching the minimum clear sidewalk width or the roadway. Plantings and shrubs should be maintained no higher than 3 ft. (1 m).

The *Roadside Design Guide* (AASHTO 2011b) encourages the use of buffer strips between urban roadways and sidewalks to physically separate pedestrians from the roadway and the use of landscaping and other roadside furniture to improve the quality of the visual setting for all roadway users and adjacent property owners. The guide recognizes that in urban, suburban and small-town rural settings where pedestrian and bicycle activity is expected, roadway design will normally incorporate street trees, furnishings, and plantings, which help create a sense of enclosure to reduce traffic speeds and increase comfort and safety for vulnerable road users (AASHTO 2011b).

Landscaping also can provide drivers visual cues about the road environment through which they are traveling. Landscape design should take into account:

- The mature size of trees and shrubs and their effect on safety, visibility and maintenance costs;
- Accommodation of landscaping within the border area given the needs of other users (e.g., access to on-street parking);

- Potential future changes in roadway cross sections;
- The impact of landscaping on visibility for motorists and pedestrians at driveways and intersections;
- Proper placement and spacing of landscape elements such as trees and shrubs away from roadside utility lines in order to avoid conflict with root systems;
- Positioning of canopy trees so they are far enough away from service wires; and
- Trimming canopy trees as needed to provide sufficient clearance height for taller vehicles.

5.2.6.3 Additional Guidance

Designing Walkable Urban Thoroughfares (ITE 2010a) recommends landscaping as a pedestrian amenity, as it can help create a distinctive identity as part of a planned streetscape project. Furthermore, spacing street trees 15 ft. to 30 ft. (5–10 m) apart in the furnishings zone can create continuous canopy for shade and aesthetics (ITE 2010a).

In areas with high pedestrian activity with active ground-floor uses, trees should be planted in tree wells covered by grates (or using other suitable cover techniques such as porous pavement) to maximize the area available for walking. Landscaping also can be incorporated as part of a curb extension in the shadow of the on-street parking lane to narrow the width of the street and improve pedestrian crossings (ITE 2010a).

Accounting for the impacts and costs of maintenance, streetscape improvements should incorporate plants that are adapted to the local climate and indigenous to the area. Trees will need to be regularly pruned to avoid interfering with pedestrians, street lighting, parked vehicles, sight distance to crossing pedestrians, or visibility of traffic control devices. Tree branches also can interfere with overhead utility wires. Burying utilities or planting trees that will have lower canopy heights at maturity can help reduce this conflict. Trees also should be chosen and planted to reduce the potential of root systems damaging sidewalks, utilities and pavement. The ITE guide recommends a minimum vertical clearance of 8 ft. above the pedestrian travel way along the sidewalk and at least 13 ft. from the top of curb in the traveled way to provide clearance for larger vehicles (ITE 2010a).

5.2.6.4 Landscaping Principles and Considerations for All Users

Landscape buffers help improve pedestrian safety and enhance the quality of the walking environment by increasing separation between vehicles and pedestrians. The furnishings zone provides room for snow storage, splash protection during inclement weather, and space for curb ramps, street lights, traffic signs and other furnishings. Buffer area plantings and benches also create inviting spaces for pedestrians. The design of landscaping should take into account:

- **Accessibility.** Landscaping should accommodate access to parked cars (when applicable) and to bus stop loading zones. When a landscape buffer at a bus stop separates the sidewalk and street, accessible paved loading pads and connections for both the front and rear doors of a bus should be provided, depending on the length of the bus stop. Street trees with high canopies generally provide sufficient minimum clearance to avoid interfering with pedestrian travel. ADA standards for clear width along sidewalks also must be maintained.
- **Maintenance.** The designs must consider the costs and effort required to maintain the plantings and avoid damaging the streetscape. For example, consistent pruning of street trees is needed to avoid interference with pedestrians on the sidewalk or tall vehicles within the roadway. Root systems also must be managed to avoid heaving the sidewalk or damaging surrounding foundations.
- **Stormwater management.** Best management practices can be incorporated to capture and treat stormwater runoff. Solutions may include vegetated swales, infiltration basins, pervious pavement, drywells and flow-through planters. Sustainable stormwater management

practices help reduce the flow and toxicity of runoff, and they are more cost-effective than conventional drainage systems.

- **Sight distance.** Low-growth plantings (generally 2 ft. high or less) can be incorporated as part of curb extensions that help calm traffic and guide pedestrians to legal crossings while maintaining the visibility of motorists and pedestrians at crosswalks.

5.2.6.5 Recommended Practice

- **Design guidance.** On low- and intermediate-speed streets in urban contexts, landscaping generally is located within the furnishings zone of sidewalks (i.e., between the pedestrian accessible route and the roadway). The potential to support landscaping and trees depends on the width of the furnishings zone and the resulting permeable surface (see Exhibit 5-29).
- **Implementation guidance.** On low- and intermediate-speed streets, using small-caliper trees alleviates concerns about fixed objects or visual obstructions between the roadway and the pathway. AASHTO (2011a) does not classify trees whose trunks grow to below 4 in. (100 mm) diameter at maturity as fixed objects (unless they are grouped closely together). Accordingly, trees of this width may be placed within the clear zone, but small-caliper trees should be placed outside the lateral offset of roadways (AASHTO 2011a). On streets and roadways at the upper range of intermediate speeds (40–45 mph) or above, safe roadside design is important to evaluate in landscape design alternatives. See Chapter 10 of AASHTO’s *Roadside Design Guide* (AASHTO 2011b).

Trees and other landscaping may affect the visibility of sidewalk users at driveways and intersections. To promote adequate sight lines ground covers should not exceed 2 ft. (0.6 m) in height. Trees generally should be set back at least 20 ft. to 30 ft. (6.0 m to 10.0 m) on the approach to intersections and 10 ft. to 20 ft. (3.0 m to 6.0 m) on the far side (Gattis et al. 2010). Trees also must be pruned so that branches do not interfere with pedestrians, street lighting, parked vehicles and traffic control devices. The minimum recommended vertical clearance is 8 ft. (2.4 m) above the pedestrian travel way (U.S. Access Board 2002).

Street trees also can introduce conflicts with overhead and underground utilities. Tree selection and training tree branch development can minimize impact to overhead utilities. Providing watering systems to encourage deep roots or root barriers can be used to reduce the potential for sidewalk damage (ITE 2004).

Because plant and tree selection can affect both maintenance costs and the aesthetic character of the roadside, designers are encouraged to select plants that are adapted to the local climate and fit the character of the surrounding area. Providing plantings in curb extension islands between parking bays helps reduce the visual width of the street and can be part of a design that maintains a wider pedestrian throughway, especially in constrained conditions.

Exhibit 5-29. Landscaping potential of various furnishings zone widths.*

Furnishings Zone Width	Landscaping Compatibility	Trees
2–4 ft. (0.6–1.2 m)	Small shrubs possible, generally appropriate for turf grass	Trees not practical within this width
4.5–6.0 ft. (1.3–1.8 m)	Large shrubs or decorative landscaping possible	Small trees become practical
> 6.0 ft. (> 1.8 m)	Supports a high degree of decorative landscaping	Large canopy trees possible

* Where on-street parking is present, curb extensions may be used to offer an enhanced landscaping area suitable for placement of bioswales and trees.

For plantings in the furnishings zone, tree wells with grates should be considered in areas with predominantly commercial ground-floor uses in order to maximize the area for pedestrian circulation.

5.2.6.6 Stormwater Management

Stormwater runoff from roadways and roadsides normally must be collected and transported within the right-of-way. Conventional stormwater treatments vary. For some communities, the conventional way is to collect and carry it in storm sewer pipe networks to a treatment plant, then to an outfall into a water body or possibly a beneficial re-use. For other communities, stormwater is controlled at the source or through treatment-control best management practices (BMPs). These stormwater collection and management techniques and practices must be coordinated with the design of facilities for transit access and for roadside users including pedestrians and bicyclists.

Increasingly, urban communities and small towns are turning to “green infrastructure” (vegetated stormwater management) in the roadside and in traveled way medians. In addition to achieving the landscaping benefits noted in the previous section, green infrastructure can help reduce the negative environmental impacts of stormwater. On multimodal urban and suburban roadways, effective green approaches to stormwater management also can improve the walking and bicycling environment and the aesthetics and perceived quality of the community. Adding value and multiple functionality, green stormwater management practices should be considered in roadway improvement projects. In addition to the other benefits of vegetated stormwater management, these systems can:

- Enhance the aesthetic appeal of streets, neighborhoods and commercial or industrial sites;
- Provide wildlife habitats;
- Reduce soil erosion; and
- Provide locations for snow storage.

Managing Wet Weather with Green Infrastructure (U.S. EPA 2008) describes typical green infrastructure applications in urban and suburban areas, which may include:

- **Stormwater planters.** Designed to collect and treat runoff from the surrounding area, stormwater planters and rain gardens rely on physical and biological systems, using mulch, soil, plant root systems and soil microbes to hold water and capture pollutants such as bacteria, nitrogen, phosphorus, heavy metals, oil and grease.

Stormwater planters and rain gardens are designed to hold standing water only for short periods of time; they should drain down to a dry surface within 24 hours of a storm event. They work best where roadway grades are relatively flat so that the water flows created during heavy rain events do not erode the collection areas. The plants selected should be tolerant of short periods of inundation, but be able to survive long dry periods, as they will generally not be irrigated. Plants also should be salt tolerant if runoff from streets or sidewalks will be captured. Planters and gardens can be lined if infiltration is not desirable or feasible, but lined planters must be designed to drain to an external structure. All planter and garden designs should include overflow structures. Plant selection should be appropriate to the surrounding context, and should be sensitive to maintenance capacity.

Stormwater planters generally are used to capture runoff from surrounding paved surfaces including sidewalks, plazas, parking lots and streets. They have structural walls and curbs, and may include retaining walls. Underdrains are incorporated into the design to keep water from building up in the soil, and overflow pipes are used to control excess flow and prevent flooding onto adjacent areas. Drains and overflows usually connect to nearby storm drains, and the planters usually have open bottoms to allow for infiltration.

As cost-effective enclosed structures that can be modified to fit almost any physical constraint, stormwater planters can be used in medians and added to the roadside design. They

also may be combined with traffic calming devices when used on curb extensions or designed as chicanes. They can be designed to accommodate trees or low vegetation depending on size and visibility constraints.

Generally, a planter is composed of the following layers: mulch, plants, a specific soil mixture, infiltration bed and the native soil. Engineered geotextile lining material may be used in some applications, but generally is not desired on the bottom of the planter as it can easily clog.

The fundamental design principles behind both stormwater planters and rain gardens reflect the fact that soils are highly porous with a high organic content to support healthy plant communities. Both planters and rain gardens that are adjacent to paved areas can include structural soil beds to increase their stormwater management capacity.

- **Rain gardens and vegetated swales.** Typically, rain gardens are simpler recessed planting beds that function like stormwater planters but have fewer structural elements. They may appear similar to conventional landscaped areas, but rain gardens will be depressed rather than elevated from the surrounding area. They can be used in areas where a more natural garden aesthetic is desired. They are commonly used in residential areas and urban settings with ample space, as rain gardens often are larger, providing opportunities for more diversity in plant life over planters.

Linear rain gardens that convey runoff to a desired location are called *vegetated swales*. Vegetated swales slow runoff velocity, filter stormwater pollutants, reduce runoff temperatures, and in low-volume conditions recharge groundwater. Vegetated swales can be used to augment traditional pipe and gutter systems.

Narrow vegetated swales, called *green gutters*, also can be constructed to capture, infiltrate and convey runoff from an adjacent sidewalk. If swales or green gutters will be used, the sidewalks should be pitched to convey the runoff into the landscape feature.

Filter strips are rain gardens that capture sheet flow from a parking lot or other paved area during smaller rain events. Filter strips are used in conjunction with an infiltration trench or other system that can capture the excess runoff during a larger rain event.

5.2.6.7 Stormwater Management Design Guidelines

Complete design guidance in relation to stormwater management is beyond the scope of this Guide. To develop an initial concept for using a green approach to stormwater management in urban contexts, designers may:

- Consider swales for use in medians, planting strips, planters, curb extension, islands or other green areas of significant size where runoff can be collected and detained until filtered or absorbed or flowed into inlets at the end of swales;
- Employ swales where they can slope downward from the curb or sidewalk;
- Design gutters and curbs so that water can enter the swale through breaks or other openings in the curbs;
- Provide for runoff to enter swales directly from adjacent sidewalks or piped from elsewhere in the right-of-way;
- Consider the appearance, cleaning, and maintenance of stormwater features along with the amount of stormwater to be handled;
- Blend stormwater BMPs in with the rest of the roadway design and context by considering pedestrian connectivity, parking, bicycle and transit needs and provisions, safety, and emergency access.

5.2.7 Lighting and Street Furniture

5.2.7.1 Lighting

Streetlights generally are installed in the roadside area. Appropriate street lighting facilitates safe movement of traffic and provides a sense of safety and security for pedestrians and bicyclists,

but when used effectively, lighting can do much more. Streetscape lighting lends character to a street, and by highlighting certain features, it can contribute to a sense of place and civic pride. Private property owners are critical participants in creating the overall streetscape lighting environment, especially for the roadside. While accounting for existing lighting levels, nighttime design needs and aesthetics, urban street lighting should complement the context and land use of the street.

The Green Book notes that lighting may reduce nighttime crashes and contribute to the ease and comfort of operation on a highway or street (AASHTO 2011a). Statistics indicate that nighttime crash rates are higher than daytime crash rates and that this may be attributed to reduced visibility at night. AASHTO also notes that there is evidence that fixed-source lighting tends to reduce crashes in urban and suburban areas, where there are concentrations of pedestrians and roadside intersectional interferences (AASHTO 2011a).

The Green Book recommends that streetlight luminaire supports (poles) should be placed outside the roadside clear zone whenever practical; but if they are located within the clear zone, they should be designed to have a suitable impact attenuation feature, normally a breakaway design. AASHTO recommends that breakaway poles should not be used on streets in densely developed areas, however, and particularly with sidewalks because struck poles could interfere with pedestrians and cause damage to adjacent buildings. Because of lower speeds and parked vehicles, the Green Book notes that there is much less chance of injuries to vehicle occupants from striking fixed poles on a street as compared to a highway (AASHTO 2011a).

In general, street lights should be provided in urban core and urban contexts where pedestrian and bicycle activity is the greatest. Lighting also should be considered in suburban and rural town contexts where it may be beneficial for the safety and comfort of any user mode. Other benefits of street lighting include:

- Creating an environment that feels safe and secure for pedestrians.
- Improving the legibility (visibility) of streets, intersections, ramps, transit stops, critical nodes and activity zones; and
- Enhancing the character of the streetscape by using fixtures that are in keeping with the image of the community.

Design considerations for street lighting include:

- Using state-of-the art technology when appropriate to provide effective, energy efficient lighting that minimizes light trespass and is dark-sky compliant;
- Using clear and consistent patterns to reinforce the direction of travel and delineate intersections;
- Using pedestrian-scale lighting (lower than 20 ft.) alone or in combination with roadway-scale lighting in high-activity areas to encourage nighttime use of the roadway by pedestrians and bicyclists; and
- Ensuring that critical locations (e.g., ramps, crosswalks, transit stops and seating areas that are used at night) are visible and lit.

5.2.7.2 *Street Furniture*

Street furniture placed along a sidewalk is an amenity that encourages walking. Street furniture such as public seating, trash receptacles and drinking fountains provide functional services to pedestrians and visual detail and interest to the context. Street furniture also conveys to other users of the roadway that pedestrians are likely to be present. When designing for street furniture, guidelines include the following (ITE 2010a):

- Street furniture may be placed within curb extensions as long as it does not obstruct the clear pedestrian throughway, access to curb ramps or sight distance at crossing locations;

- Bicycle parking or landscaped areas with seating walls can be accommodated in curb extensions;
- Street furniture should be placed on thoroughfares expected to have high pedestrian activity;
- Placement of furniture should not reduce the width of the clear pedestrian throughway to less than 5 ft., or intrude into the operational offset for objects behind the curb (typically 1.5 ft. minimum from the face of curb) (AASHTO 2011b);
- Placement of furniture should be evaluated for impacts on sight distance at intersections and driveways; and
- Placement of non-breakaway furniture should be evaluated carefully on higher-speed roadways in consideration of guidance in the *Roadside Design Guide* (AASHTO 2011b).

The most beneficial uses and locations for street furniture include:

- Transit stops,
- Major building entries,
- Retail and mixed-use main streets, and
- Restaurant areas.

5.2.8 Utilities

Utilities are a necessary part of the roadway design process in all contexts, urban, suburban and rural. Telecommunications, electric transmission, street lighting conduit, traffic signal conduit, and fiber optic conduit often are located under the sidewalk. Lateral lines extend from water, sewer and gas utility mains in the public rights-of-way to serve adjacent properties. Whether placed overhead, underground or both, utilities can significantly impact the design of all elements of the roadway. In urban core, urban and suburban areas, utilities particularly affect roadside elements. Often, the portion of the right-of-way available to the roadside is less than preferred, and roadside facilities must be carefully coordinated with a multitude of utilities.

The benefits of well-organized and coordinated utility design/placement include:

- Reduced clutter in the roadside,
- Improved pedestrian safety and visual quality,
- Increased opportunity for planting areas and adequate soil volume to support tree growth and stormwater infiltration, and
- Reduced maintenance conflicts.

5.2.8.1 Current AASHTO Policy and Guidance

The Green Book provides the following observations and guidelines regarding coordination with utilities in the right-of-way during the roadway design process (AASHTO 2011a):

- Because of restricted space in most metropolitan areas, special consideration should be given in the initial design to the potential for joint usage of the right-of-way that is consistent with the primary function of the highway or street.
- Appurtenances to underground installations, such as vents, drains, markers, manholes, and shutoffs, should be located so as not to be a roadside obstacle, not to interfere with highway or street maintenance activities, and not to be concealed by vegetation. Preferably, they should be located near the right-of-way line.
- Where there are curbed sections, utilities should be located in the border areas between the curb and sidewalk, at least 1.5 ft. behind the face of the curb, and where practical, behind the sidewalk.
- Where shoulders are provided rather than curbs, a clear zone commensurate with rural conditions should be provided.
- Existing development and limited right-of-way widths may preclude location of some or all utility facilities outside the roadway of the street or highway.

- Under some conditions, it may be appropriate to reserve the area outside the roadway exclusively for the use of overhead lines, with all other utilities located under the roadway. In some instances, locating all the facilities under the roadway may be appropriate.
- The location of underground and above-ground utilities must be considered when planning new landscaped areas in the right-of-way. Each jurisdiction should establish guidelines to organize and standardize utility location and to minimize conflicts between landscaping and utilities based on input from all involved departments and agencies.
- The majority of underground utilities, including sanitary sewers and storm drains, and water, gas, and electrical mains, are typically located under the roadway. Sanitary sewers are often in the center of the street directly under the potential location of a landscaped median. They are usually relatively deep. In general, if they have at least 4 ft. or 5 ft. of cover, they should not be affected by the introduction of a landscaped median. The other utilities within the roadway are typically located closer to the curbs.

5.2.8.2 *General Guidelines and Considerations for Utilities in the Urban or Suburban Roadside*

AASHTO also provides the following general guidelines for coordinating utilities in urban and suburban roadways (AASHTO 2011a, AASHTO 2005):

- Utilities should be located to minimize disruption to pedestrian travel and to avoid ideal locations for directing stormwater, planting trees and other vegetation, and siting street furniture, while maintaining necessary access to the utilities for maintenance and emergencies.
- Utility main lines that run laterally under the sidewalk should be located in a predetermined zone to minimize conflicts with tree roots and planting areas. The ideal location to minimize conflicts with trees would be under the pedestrian or frontage zones, although the more practical location is often under the furniture zone. Stacking dry utilities (telephone, cable television [CATV], electric, etc.) in the pedestrian or frontage zones will further reduce conflicts with the landscaped area.
- Utility laterals should not typically run directly under landscaped areas in the furniture zone, but instead under driveways and walkways wherever possible.
- Vaults in the pedestrian zone should have slip-resistant covers. Large flush utility vaults should be placed at least 3 ft. from the building and 4 ft. from the curb where sidewalk widths allow. Surface-mounted utilities should not be located in the pedestrian zone.
- Utility vaults in the frontage zone should ideally not be located directly in front of building entrances.
- Utility vaults and valves should be minimized in curb extensions where plantings or street furnishings are planned.
- Surface-mounted utilities may be located in curb extensions outside of crossings and curb ramp areas to create greater pedestrian through width.
- New utility structures should not be placed within street crossing and curb ramp areas.
- Catch basins and surface flow lines associated with storm drainage systems should be located away from the crosswalk or between curb ramps. Catch basins should be located upstream of curb ramps to minimize ponding at the bottom of the ramp.
- Street lighting and traffic signals should share poles wherever possible. When retrofitting existing streets or creating new streets, pursue opportunities to combine these poles.
- Utility appurtenances should not interfere with pedestrian circulation, block entrances to buildings or curb cuts, or interfere with sight distance triangles.
- Above-ground utilities should be placed at least 18 in. from the back of curb and may not interfere with the minimum pedestrian throughway. If buildings do not abut the right-of-way, place utilities behind the sidewalk, where they will not interfere with the use of the adjacent property.

Refer to *A Guide for Accommodating Utilities Within Highway Right-of-Way, 4th Ed.* (AASHTO 2005) for additional information on the design and placement of utilities in all contexts.

5.2.9 Driveway Access

Driveways provide vehicle access to businesses and residences located along roadways. However, turning vehicles create conflict points with pedestrians along sidewalks and with bicyclists if sidepaths or shared-use paths exist. Driveway design details can help prioritize pedestrian movements, lower vehicle speeds, maximize visibility of all modes and reduce crash potential.

5.2.9.1 Current AASHTO Policy and Guidance

The Green Book states, “An objective of driveway design is to seek a balance that minimizes conflicts among motorized vehicles, bicycles, and pedestrians and accommodates the demands for travel access” (AASHTO 2011a). Driveways should be designed with the objective of maintaining roadway operations and efficiency, providing reasonable property access, accommodating bicycle lanes or paths when present, allowing efficient travel for sidewalk users, maintaining sight distance between vehicles and pedestrians or other roadway users, and maintaining public transit stops (where applicable).

The Green Book considers driveways similar to low-volume intersections but with the need for additional design considerations to determine grade, width, channelization and cross slope, taking into account the street’s functional classification and adjacent land uses. Driveways must be designed with adequate widths, throat dimensions and proper layouts to accommodate the anticipated usage. The vertical alignment of the driveway must take into account the sidewalk cross slope designed to accommodate pedestrians with disabilities while allowing for efficient vehicle operation. The driveway should allow adequate drainage to minimize ponding where the driveway interfaces with the sidewalk and the main roadway. Sight distance should be maintained by limiting the presence of unnecessary roadside structures, such as advertising signs or billboards.

The Green Book recommends not locating driveways within the vicinity of an intersection or adjacent driveways in order to reduce the need to monitor multiple conflict areas in a short distance and reduce potential conflicts (AASHTO 2011a). Minimizing the number of driveways to each parcel by consolidating access points or by providing access from a side street or access road can help achieve desired spacing on urban and suburban roadways.

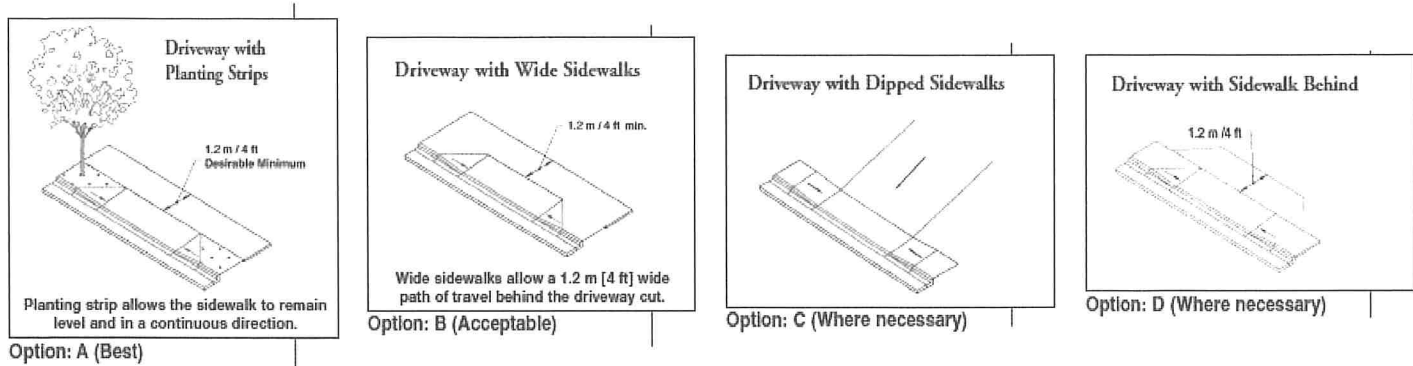
The Pedestrian Facilities Guide states that driveway ramps should be designed to preserve access for pedestrians with disabilities (AASHTO 2004b).

The Pedestrian Facilities Guide prefers conventional flared driveways for property access to enhance pedestrian safety and comfort, compared to intersection-style driveways with turning radii, and clearly indicate the pedestrian right-of-way. Conventional driveways encourage motorists to slow down when entering the driveway and reduces the reaction time needed to stop for pedestrians.

The Pedestrian Facilities Guide recommends one of four driveway types (see Exhibit 5-30) to meet ADA accessibility requirements by maintaining a minimum 4-ft. (1.2-m) continuous path along the sidewalk alignment, or by providing an area adjacent to the main walk that maintains a 2 percent cross slope.

Additional driveway design considerations from the Pedestrian Facilities Guide include (AASHTO 2004b):

- Placing the driveway ramp in the sidewalk furnishings zone to maintain a continuous level walkway and providing more turning area for entering and exiting vehicles;

Exhibit 5-30. Driveway types in the AASHTO Pedestrian Facilities Guide.

Source: AASHTO (2004b)

- Narrowing a wide sidewalk only at the driveway to maintain a 4-ft. travel path behind the driveway cut;
- Building curb ramps at a maximum 8.33 percent slope between the sidewalk and driveway if there is insufficient space to achieve the desired 2 percent cross slope; and
- Obtaining an easement from the adjacent property owner if necessary to construct a level sidewalk area behind the driveway aprons.

The Pedestrian Facilities Guide discourages the use of intersection-style driveways at uncontrolled locations. If they are deemed necessary, the following design elements can mitigate negative impacts to pedestrian travel (AASHTO 2004b):

- Continuing the sidewalk material across the driveway while maintaining sidewalk height and grade to provide a visual cue to motorists that they are entering a pedestrian area;
- Minimizing corner radii of the curb to reduce vehicle speeds; and
- Narrowing driveway widths as much as possible to reduce pedestrian exposure.

5.2.9.2 Driveway Principles and Considerations for All Users

The Pedestrian Facilities Guide recognizes that “uncontrolled access across a sidewalk not only degrades the quality of the pedestrian environment, but also increases the potential for vehicle-pedestrian conflicts” (AASHTO 2004b). Attributes of well-designed driveways include:

- **Design.** Conventional driveway designs are strongly preferred in areas with high multimodal priority, as the design reinforces the pedestrian right-of-way and reduces vehicle turning speeds. When intersection-type driveways are used, narrowing the curb radii to 10–15 ft. and using high-visibility crosswalk markings helps meet the same design objectives.
- **Accessibility.** When a sidewalk crosses a driveway, the pedestrian clear zone must be a minimum of 4 ft. in width (with additional width preferred) to maintain accessibility for pedestrians with disabilities. The cross slope of the sidewalk through the driveway must be no greater than 2 percent.
- **Access management.** Placing multiple driveways in close proximity to each other or to nearby intersections is not compatible with high pedestrian activity. Consolidating or closing driveways, installing continuous medians to prohibit left-turn movements, or moving access points to side streets can enhance the pedestrian environment and reduce potential conflicts with vehicles.
- **Reduce exposure.** The total width for two-way driveways generally should be a maximum of 24 ft. (14 ft. for one-way driveways) unless the volume and type of traffic requires more lanes or wider lanes. Where driveway volumes warrant multiple lanes in each direction, providing a separating median between directions can provide a pedestrian refuge (ITE 2010a).

- **Sight distance.** Roadside objects should not block the visibility of motorists or pedestrians at driveways. Prohibiting curbside parking adjacent to the driveway expands the sight triangle for motorists exiting the driveway onto the roadway.

5.2.9.3 Recommended Practice

- **Design guidance.** The preferred design of uncontrolled driveways is a conventional style with the driveway apron contained fully within the furnishings zone of the sidewalk corridor. The ability to provide a preferred design is directly related to the width of the sidewalk. For more information about sidewalk design, see the section in this chapter on “Pedestrian Accommodations.” Exhibit 5-31 identifies preferred driveway design types in response to sidewalk width.

Uncontrolled intersection-type driveways should be avoided in any areas where multimodal accommodation is desired. Signalized intersection-type driveways are suitable for large traffic generators. When used, intersection-type driveways should incorporate pedestrian-oriented design treatments to lower turning speeds, reduce pedestrian crossing distance and improve sight distance (AASHTO 2004b). Pedestrian-oriented treatments include:

- Crosswalks that are well-marked and visible to motorists;
 - Signage placed as necessary to remind motorists of their duty to yield to pedestrians when turning; and
 - A narrow curb radius (e.g., 10 ft. to 15 ft. [3–4.5 m]) when truck volumes are low. When truck volumes are higher, the curb radius can be increased and the stop bar should be set farther back to allow clearance for wide turns.
- **Implementation guidance.** Designers should keep in mind that an excessive grade change between the cross slope of the roadway and the driveway grade may result in the underside of a vehicle dragging on either a crest or sag alignment (Gattis et al. 2010).
NCHRP Report 659: Guide for the Geometric Design of Driveways provides additional guidance on driveway design and interaction with the roadside and its users. Some general considerations for designers include the following (Gattis et al. 2010):
 - Access management elements such as driveway consolidation and turn restrictions can reduce the number of conflict points between motorists and other roadway users. A raised median allows for only right-in/right-out vehicle movements, which reduces conflict points by redirecting motorists to nearby traffic-controlled intersections.

Exhibit 5-31. Preferred driveway design by sidewalk width.

Total Sidewalk Width	Preferred Design	Critical Dimensions
10 ft. (3.0 m) or larger	Conventional style with driveway slope contained within furnishings zone (Option A)	5 ft. (1.5 m) minimum pedestrian through zone maintains a continuous level walkway
7 ft. to 9 ft. (2.1–2.7 m)	Conventional style driveway Driveway slope may need to encroach into pedestrian through zone (Option B).	4 ft. (1.2 m) minimum pedestrian through zone required
5 ft. to 6 ft. (1.5–1.8 m)	Conventional style driveway with wraparound sidewalk (Option D) <i>Optional:</i> Dipped sidewalk style (Option C)	4 ft. (1.2 m) minimum pedestrian through zone required

Source: Midwest Research Institute (MRI Global)

- The appearance of the sidewalk (e.g., a scoring pattern or special paving) should be maintained across driveway and alley access points to indicate that, although a vehicle may cross, the area traversed by a vehicle remains part of the pedestrian travel way.
- Ideally, the width of driveways intended for two-way traffic should not exceed 24 ft. unless a specific frequent design vehicle requires a wider dimension. Some driveway volumes will warrant two lanes in each direction. In these cases, the designer may consider designing a median between directions to separate opposing traffic and to provide a pedestrian refuge. When a driveway is one-way only, a maximum width of 14 ft. should be considered.

5.2.10 Bridges

Bridges connect destinations in communities and provide access to emergency and essential services, yet many of the nation's existing bridges do not provide safe and comfortable accommodations for people who are walking and biking. Bridges that lack pedestrian and bicycle accommodations can force substantial detours or sever routes entirely, discouraging or eliminating the option to walk and bike for transportation. Pedestrians and bicyclists who do travel on bridges without proper accommodations may increase their risk of being involved in a crash. Incorporating pedestrian and bicycle facilities as part of bridge rehabilitation projects can improve safety for everyone while providing all road users direct and safe connections to schools, jobs, parks, health care services and other destinations.

Bridge rehabilitation projects are opportunities to create critical connections in existing pedestrian and bicycle networks or provide safer and more comfortable facilities for non-motorized users. Bridge projects also are high-profile, large-scale projects, and the inclusion of bicycle and pedestrian facilities can serve as recognition of the role of bicycling and walking in transportation networks.

In general, major capital projects at bridge locations are infrequent, with many years or decades between infrastructure upgrades. Given the long lifespan of a bridge compared to a typical section of road, it is especially important that bridge rehabilitation projects consider bicycle and pedestrian access and connectivity. Bridges can be upgraded at locations where facilities like sidewalks or greenways are planned but are not yet present, with the understanding that surrounding multimodal network connections will improve over time.

Bicycle and pedestrian facilities can be added to bridge retrofits during project alternatives analysis and identified as part of the public engagement process. It is critical to consider the bridges not as standalone structures, but rather as elements of the pedestrian and bicycle network. Planning non-motorized networks should involve identifying key barriers (e.g., waterways, railroads and major roadways) and recognizing that the bridges spanning these features are a key element of multimodal network improvement strategies.

National guidance supports the inclusion of bicycle and pedestrian facilities on bridges. The following statements appear in:

- Federal law (23 USC §217(e)):

In any case where a highway bridge deck being replaced or rehabilitated with Federal financial participation is located on a highway on which bicycles are permitted to operate at each end of such bridge, and the Secretary determines that the safe accommodation of bicycles can be provided at reasonable cost as part of such replacement or rehabilitation, then such bridge shall be so replaced or rehabilitated as to provide such safe accommodations.

- The Bicycle Guide (AASHTO 2014b):

[b]ridges, viaducts, and tunnels should accommodate bicycles. There are numerous examples of limited-access highway bridges that cross major barriers (such as wide waterways) that incorporate a

shared-use path for bicyclists and pedestrians. The absence of a bicycle accommodation on the approach roadway should not prevent the accommodation of bicyclists on the bridge or tunnel.

- The Pedestrian Facilities Guide (AASHTO 2004b):

Provisions should always be made to include some type of walking facility as a part of vehicular bridges, underpasses, and tunnels, if the facility is intended to be part of a pedestrian access route.

Early consideration of bicycle and pedestrian elements in the bridge planning project can ensure that the upgraded facility sufficiently meets the needs of all road users. Pedestrian and bicycle needs should be considered early in the planning and project development process as this is often when it is most feasible to include substantial safety-related improvements. Delaying consideration of these components until the final design or construction phases may limit the accommodations that are possible for non-motorized road users.

Ideally, bridge designs should provide adequate width for current and anticipated pedestrian and bicycle use. Sufficient clear width and usable width should be provided. The desirable clear width for a sidewalk on a bridge is 8 ft. (AASHTO 2004b). The minimum width for one-way bicycle travel is 4 ft. (AASHTO 2014b). Clear width is a traveled way clear of obstructions such as railings, light poles, signs, and so forth (TRB 2010). The usable width recognizes that pedestrians and bicyclists will not travel at the very edge of a traveled way or immediately against a railing, but need at least 1.5 ft. of shy distance from vertical objects such as bridge railings (TRB 2010). Because bicyclists have a higher center of gravity than pedestrians do, railings should be a minimum of 42 in. high. Where a bicyclist's handlebar or pedal may come into contact with the railing, a smooth, wide rub-rail should be installed (AASHTO 2014b). On bridges that accommodate both vehicular and pedestrian/bicycle travel, only a crash-tested railing should be installed.

Including bicycle and pedestrian facilities on bridges is not always possible. Each bridge is unique, with differing infrastructure, surrounding land use, community support and context-specific challenges. These facilities cannot be accommodated in all bridge rehabilitation projects, and when they are included, the extent and configuration of the bicycle and pedestrian facility should match the need and opportunity. In addition, the decision to include a sidewalk, path or bicycle lane on a bridge should account for the surrounding bicycle and pedestrian network.

In this Guide, Chapter 4 also includes a section on bridges that includes additional guidance on pedestrian and bicycle accommodation.

5.2.11 Railroad-Highway Grade Crossings

Pedestrians and bicyclists in the roadside also must navigate rail crossings. The designer should pay particular attention to the width and surface of a roadside crossing to ensure that it meets minimum requirements to allow walkers, bicyclists, or persons with disabilities access to cross the railroad tracks. Where active crossing protection is provided for motorized vehicles, active crossing techniques also should be applied to protect non-motorized users of the roadway.

5.2.11.1 Bicycles

Depending on the angle and type of crossing, a bicyclist may lose control of the bike if the wheel becomes trapped in the rail flangeway. Designing to ensure bicycle-friendly track crossings applies wherever streetcar or light rail tracks turn across a bikeway (including any bicycle lane, bike boulevard or cycle track), wherever bikeways turn across tracks, and at any intersection where bicycle turns are accommodated (especially where two bike lanes intersect).

Bicycling adjacent to tracks also can pose dangers, which are particularly pronounced when a bicyclist must be prepared to swerve to avoid unforeseen obstacles (e.g., opening vehicle

doors). Bike-friendly trackway design also applies to all mixed-traffic streetcar/trolley and LRT running ways.

The *Transit Street Design Guide* (NACTO 2016) provides several design recommendations for keeping bicyclists safe at rail crossings. Information is provided in the section on “Railroad-Highway Grade Crossings” in Chapter 4 of this Guide.

5.2.11.2 Pedestrians

Providing for the safety of pedestrians crossing railroads is the most difficult because of the relative ease with which pedestrians can go under or around lowered gates. Pedestrians typically seek the shortest path and, therefore, may not always cross the tracks at the designated highway or pedestrian crossing. Given the variety of factors that may contribute to pedestrian hazards, detailed studies often are necessary to determine the most effective measures to provide for pedestrian access and safety at specific locations. A variety of preventive design measures can be employed, as discussed in this section. ADA guidelines for accessible design provide many geometric features pertaining to pedestrian facilities that address minimum widths and clearances, accessible routes and pedestrian pathways, curb ramps and protruding objects (U.S. Access Board 2011).

As noted in Chapter 4, collisions between LRVs and pedestrians occur less frequently than collisions between LRVs and motorized vehicles; when they do occur, however, they are more severe. Furthermore, pedestrians are not always completely alert to their surroundings, and LRVs are nearly silent when operating in a street environment. Appropriate pedestrian crossing control systems are critical for pedestrian safety when crossing LRT tracks. The following design references provide information on crossing treatments that may be warranted at rail-pedestrian crossings:

- *Guide for Geometric Design of Transit Facilities on Highways and Streets* (AASHTO 2014a);
- *TCRP Report 17: Integration of Light Rail Transit into City Streets* (Fitzpatrick et al. 2015a);
- *Transit Street Design Guide* (NACTO 2016);
- *TCRP Report 183: A Guidebook on Transit-Supportive Roadway Strategies* (Ryus et al. 2016);
- *TCRP Report 175: Guidebook on Pedestrian Crossings of Public Transit Rail Services* (Fitzpatrick et al. 2015b);
- *TCRP Report 117: Design, Operation, and Safety of At-Grade Crossings of Exclusive Busways* (Eccles and Levinson 2007); and
- *TCRP Report 112/NCHRP Report 562: Improving Pedestrian Safety at Unsignalized Crossings* (Fitzpatrick et al. 2006).

5.2.12 Traffic Control Devices and Operations

Roadside users encounter particular challenges when crossing public street intersections. When interacting with larger and faster motorized vehicles, roadside users are clearly vulnerable and must be extremely cautious when entering and crossing vehicle-dominated traffic lanes. Special traffic signal indications, signs and markings can provide some level of support and comfort to crossing pedestrians and bicyclists, but it is still the vulnerable users' responsibility to cross streets and roadways with extreme caution. The roadway designer should recognize this challenge and provide the best accommodation possible when designing the roadside interaction with the traveled way. In contexts with significant volumes of pedestrian and bicycle traffic, fixed-time signal operation or pedestrian recall operation should be considered to better accommodate those users.

If applied properly, traffic control design and operations guidance from the Pedestrian and Bicycle Information Center (<http://www.pedbikeinfo.org/>) will help to reduce crash risks for

roadside users in the traveled way (PBIC n.d.) (Fitzpatrick et al. 2015a). The MUTCD (FHWA 2009b) also provides a wealth of guidance to the designer in the design and operation of traffic control devices (e.g., signs, signals and markings) for pedestrians and bicyclists.

5.2.12.1 Pedestrian Signals

Pedestrian signals should be clearly visible to the pedestrian at all times when in the crosswalk or waiting on the far side of the street. Large pedestrian signals can be beneficial in some circumstances (e.g., where the streets are wide). Use of the international pedestrian symbol signal is preferable and recommended in the MUTCD (FHWA 2009b). Existing “WALK” and “DON’T WALK” message signals may remain for the rest of their useful life, but countdown pedestrian indications are required for all newly installed traffic signals where pedestrian signals are installed. They must be designed to begin counting down at the beginning of the clearance (flashing “DON’T WALK”) interval and can operate on a fixed-time or pushbutton basis. Countdown signals have been demonstrated to reduce the number of pedestrians who begin to cross when only a few seconds remain (Markowitz and Sciortino 2006).

Pedestrian detectors at traffic signals may involve pushbutton or passive detection devices (which register the presence of a pedestrian in a position indicative of a desire to cross without requiring the pedestrian to push a button). Pedestrian pushbuttons should be well designed, operable by pedestrians with visual disabilities, and within reach and operable from a flat surface for pedestrians in wheelchairs. They should be placed conveniently in the area where pedestrians wait to cross, and they should clearly indicate which pedestrian signals will be activated by the button. Quick response to the pushbutton or feedback to the pedestrian registering the signal’s actuation should be programmed into the system. Section 4E.09 of the MUTCD (FHWA 2009b) provides detailed guidance about the placement of pushbuttons.

Given that pushbutton pedestrian signal devices are activated only by about one-half of pedestrians (and even fewer are activated where the pedestrians perceive sufficient motorized vehicle gaps), new “intelligent” microwave or infrared pedestrian detectors have begun to be used in some locations. These devices automatically activate the red traffic and “WALK” signals when pedestrians are detected. Some detectors, including pedestrian user-friendly intelligent crossings (PUFFIN crossings), also can detect slower moving pedestrians in the crosswalk and extend the crossing time accordingly. Automatic pedestrian detectors have been found to improve pedestrian signal compliance and to reduce pedestrian conflicts with motorized vehicles. They are still considered experimental, however, and their reliability may vary under differing environmental conditions.

Accessible pedestrian signals (APS) can provide supplemental information in non-visual formats (e.g., audible tones, speech messages and/or vibrating surfaces) as described in the MUTCD (FHWA 2009b). More extensive information on the use of APS and the types of APS technologies now available can be found in *NCHRP Web-Only Document 150: Accessible Pedestrian Signals: A Guide to Best Practices (Workshop Edition)* (Harkey et al. 2010).

5.2.12.2 Signal Timing

Signals provide positive guidance to pedestrians regarding the interval of time permitted for crossing a street and can be used to prohibit pedestrian crossings when conflicting traffic may impact pedestrian safety. As detailed on the “Pedestrian Signals” webpage of the PBIC web site (PBIC n.d.), signal phasing options for pedestrians include the following:

Signal Coordination

This measure involves timing the phasing of adjacent traffic signals along a corridor to control the speeds of motorized vehicles. For example, the sequence of green signal cycles can be timed to speeds of 20 mph or 25 mph.

Concurrent Phasing

Pedestrian signal phase activates simultaneously with the parallel vehicle phase, permitting motorists to turn left or right across pedestrians' paths after yielding to pedestrians.

Exclusive Pedestrian Phasing

When vehicles are stopped on all approaches to an intersection, pedestrians are given a WALK indication. This phasing is referred to as "exclusive" or as a "pedestrian scramble." Intersections with pedestrian scramble phases often feature pedestrian crossing markings indicating [that] pedestrians may walk diagonally across the intersection. Exclusive pedestrian timing has been shown to reduce pedestrian crashes by 50 percent in some downtown locations with heavy pedestrian volumes and low vehicle speeds and volumes.

Split Phasing

The vehicular green phase is split into two parts: (1) pedestrians receive protected walk time while vehicles traveling parallel are given a green signal to go straight but not turn, and (2) the pedestrian DON'T WALK is activated when vehicles are permitted to turn. A study by the New York Metropolitan Transportation Council suggests that the split phasing significantly reduces pedestrian conflicts, crashes and illegal pedestrian crossings.

Leading Pedestrian Interval (LPI)

An LPI gives pedestrians an advance walk signal several seconds before motorists get a green signal, giving the pedestrian protected time to start walking in the crosswalk before a concurrent signal is provided to vehicles. This [option] makes pedestrians more visible to motorists and motorists more likely to yield to them. Typical LPI settings provide 3 to 6 seconds of advance walk time. LPI has been used successfully in several places, such as New York City, for two decades. Studies have demonstrated that LPI reduces conflicts and crashes for pedestrians. To be useful to pedestrians with vision restrictions, an LPI needs to be accompanied by an audible signal to indicate the WALK interval. There are some situations [in which] an exclusive pedestrian phase may be preferable to an LPI, such as when high-volume turning movements conflict with pedestrians crossing.

Hot Response

A hot response detector activates a pedestrian signal immediately upon actuation, subsequent to providing at least the minimum allowable green time for conflicting vehicles. Hot response signal phasing is desirable where pedestrian crossing volumes are significant or high pedestrian compliance is desirable. [This option] may be particularly appropriate at mid-block crossing locations where the distance to other signalized crossings is significant. Hot response signals also help reduce unnecessary delay for both pedestrians and vehicles at locations where pedestrians will typically use the pushbutton, but cross before the pedestrian signal is active.

Left Turn Phasing

Use of concurrent, protected/permissive, or protected left turn phasing provides different levels of conflict reduction with parallel pedestrian movements. These variations on left turn signal phasing provide increasing levels of conflict reduction between vehicles and pedestrians using a parallel crossing.

In general, longer walk intervals paired with shorter cycle lengths (ideally less than 90 seconds) provide better service to pedestrians and encourage better signal compliance. For optimal pedestrian service, fixed-time signal operation or automatic pedestrian recall mode usually works best because it provides an automatic, recurring pedestrian phase.

Pedestrians usually receive more frequent crossing opportunities (and experience less delay) with concurrent signal phasing than with exclusive signal phasing, which must service vehicle traffic and pedestrian volumes separately. When pedestrians are required to wait a long time for a pedestrian interval, many will simply choose to ignore the signal and cross during a gap in traffic, thus negating the potential safety benefits of the exclusive signal. Without accessible pedestrian signal technology, exclusive pedestrian phases also introduce a problem for pedestrians with visual restrictions because the audible cues associated with parallel traffic streams can lead pedestrians to cross at inappropriate times.

Pedestrian countdown signals can help reduce pedestrian crossings near the end of the pedestrian phase. The use of "WALK/DON'T WALK" pedestrian signal indications at signal locations can be important in many cases, including when vehicle signals are not visible to pedestrians,

when signal phasing is complex (e.g., a dedicated left-turn signal exists for motorists), at established school zone crossings, when an exclusive pedestrian interval is provided, and for wide streets where pedestrian clearance information is considered helpful. Considerations in pedestrian signal selection include the following:

- Signals must be visible/accessible to pedestrians.
- Ideally, every signalized intersection should have pedestrian signal heads.
- When possible, provide a walk interval for every cycle.
- Provide supplemental non-visual guidance for pedestrians with sensory restrictions.
- Pedestrian pushbuttons must be well positioned and within easy reach for all approaching pedestrians.
- Marked crosswalks should be installed in conjunction with pedestrian signals.
- Signal timing must also consider the needs of trucks, buses, and other motorized vehicles.
- Signal timing also needs to account for vehicle volumes, including volumes of right- and left-turn motorists.
- Illuminated “NO TURN ON RED” signs at heavy pedestrian crossings also are recommended.

5.2.12.3 *Bicycle Signal Indications*

Bicycle signal heads may be installed at signalized intersections to indicate bicycle signal phases and other bicycle-specific timing strategies. Bicycle signals should only be used in combination with an existing conventional traffic signal or hybrid beacon. Similar to conventional traffic signals, bicycle signal heads use red, yellow and green lenses with a stenciled bicycle icon. The Bicycle Facilities Guide (AASHTO 2014b) indicates that a standard three-lens signal head with a supplemental plaque that says “BICYCLE SIGNAL” can be used. Bicycle riders may also use pedestrian signals where they exist for shared-use paths, and, where high-volume bicycle facilities exist, pedestrian crossings of that facility may need to be signalized.

A bicycle signal should be considered in the following scenarios:

- At intersections with bicycle-specific movements (e.g., a contra-flow bicycle lane or cycle track), a bicycle signal may be necessary to indicate right-of-way to the bicyclist.
- At intersections where bicycle movements need to be separated in time from a conflicting vehicular movement (e.g., locations with a high volume of left- or right-turns), bicycle signals can allow for a separate bicycle phase or movement.
- At locations with high vehicle turning volumes, cyclists could benefit from a bicycle signal with a leading bicycle interval (LBI). Similar to the LPI, the LBI provides bicyclists at the intersection several seconds of green time, effectively allowing them a head start before the concurrent vehicular signal turns green. The LBI reduces the risk of conflicts between bicyclists and turning traffic and provides bicyclists an opportunity to make a lane change or left turn.
- At intersections with high bicycle volumes where bicyclists would otherwise follow the pedestrian indication (e.g., shared-use path crossings), a bicycle signal can reduce confusion. Pedestrian signal timing is inappropriate for bicyclists who travel at higher speeds, and a bicycle signal can allow bicyclists to cross legally during most of the flashing “DON’T WALK” interval.
- At intersections where bicyclists normally would follow the vehicular indication, a bicycle signal can provide a longer clearance interval more suitable to bicyclists’ speeds, making it less likely for bicyclists to be caught in the path of an oncoming vehicle.

Bicycle signal heads may be used to improve safety and operations at signalized intersections where bicycles require specific guidance. Considerations include:

- Placing the bicycle signal in a location clearly visible to oncoming bicyclists, who will have varying lateral positions on the bicycle facility;

- Ensuring that, where bicycle signals separate bicycle through movements from vehicular turning movements (or where an LBI is provided), there is no right turn on red;
- Providing an adequate clearance interval for the bicycle signal (generally determined by considering intersection width and bicyclist travel speed); and
- Installing bicycle signals with an appropriate detection and actuation system if the bicycle phase is not set to recall each cycle. Preferably, the detection and actuation system will be passive (i.e., bicyclists will not have to dismount and use a pushbutton).

5.2.13 Snow Removal and Storage

During and after a snowstorm, most snow plows operate in emergency or “hurry-up” mode, focusing on opening up lanes for motorized vehicles. Often, when snow is scraped from the vehicular lanes, it is piled up in or alongside the roadsides, thus making it difficult for bicyclists and pedestrians to use any roadside facilities that have been provided for them. Adding to the problem, piled snow can create sight distance restrictions.

Snow and ice blockages can force pedestrians onto the street at a time when walking in the roadway is particularly treacherous. Many localities that experience regular snowfalls have enacted ordinances requiring homeowners and businesses to clear the sidewalks fronting their property within a reasonable time after a snowfall occurs, and to maintain clear pathways, including areas set aside for bicycle racks. In addition, many public works agencies have adopted snow removal programs that ensure that the most heavily used pedestrian routes are cleared, including bus stops and curb ramps at street crossings, so that snow plows do not create impassable ridges of snow.

Designs for the traveled way and roadside should proactively incorporate provisions to facilitate snow clearance and storage that accommodates all modes, with pedestrians, bicyclists, and transit users given the same attention as motorists. Streets and sidewalks should remain accessible for elderly people, young children, people with disabilities, and people pushing carts and strollers.

Sidewalks and bikeways should have clear, unobstructed, accessible pathways. Particular attention should be given to clearing curb ramps at crosswalks. Hydrants, catch basins, crossing islands, medians and building entrances also must be accessible.

The following best practices are suggested for the design of roadways with pedestrian and bicycle travel in snow-belt regions:

- Design roadsides to accommodate a normal level of plowed snow behind the curb without blocking the pedestrian throughway. A wide planting strip or furnishings zone can accommodate plowed snow.
- Avoid placing objects in the furnishings zone that interfere with the ability to plow snow onto the roadside (e.g., large raised planters, continuous hedges and large utility and traffic control cabinets). Objects that snow can wrap around include trees, signs and light poles.
- Design the furnishings zone with hardscape or setback plantings and trees beyond the plow line where localities use salt to treat the streets, as roadside landscaping can be adversely affected by the salt mixture.
- Take advantage of wide greenscape/furnishings zones and curb extensions, which provide space to store snow (and both sidewalk and roadway snow clearance operations can use this storage area).
- Incorporate vertical elements (e.g., pedestrian signal poles and hydrants located on curb extensions) that can provide visual cues to snow-plow operators of changes in the curb-line.
- Use smooth materials (e.g., concrete), which are easier to shovel compared to bricks or pavers.

- Pitch roadways toward catch basins located on the upstream side of curb ramps to prevent pooling at the base of the ramp.
- Use greenscape elements (e.g., tree pits, stormwater planters and rain gardens) and pervious materials that assist in accelerating the removal of snow and ice.
- Ensure that street furniture and other physical obstructions do not clutter the pedestrian zone.

Sources of Additional Information

These publications are cited in the *Older Driver Highway Design Handbook* (FHWA 1998), which is discussed in this chapter:

- Bailey, S. S., et al. 1992. Issues of Elderly Pedestrians. *Transportation Research Record*, No. 1375, Transportation Research Board of the National Academies, Washington, D.C.
- Council, F. M., and C. V. Zegeer. 1992. *Accident Analysis of Older Drivers and Pedestrians at Intersections-Task B Working Paper*. Publication No. DTFH61-91-C-00033, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.
- Hoxie, R.E., and L. Z. Rubinstein. 1994. Are Older Pedestrians Allowed Enough Time to Cross Intersections Safely? *Journal of the American Geriatrics Society*, 42(3), pp. 241–244.
- Knoblauch, R., et al. 1995. *Older Pedestrian Characteristics for Use in Highway Design*. Publication No. FHWA-RD-93-177, Federal Highway Administration, U.S. Department of Transportation, Washington, DC.
- Parsonson, P. S. 1992. *NCHRP Synthesis Report 172: Signal Timing Improvement Practices*. Transportation Research Board of the National Academies, Washington, D.C.
- Sheppard, D., and M. Pattinson. 1986. *Interviews with Elderly Pedestrians Involved in Road Accidents*. Transportation and Road Research Laboratory, Publication No. 98, Crowthorne, UK.
- Tobey, H. N., E. M. Shungman, and R. L. Knoblauch. 1983. *Pedestrian Trip Making Characteristics and Exposure Measures*. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.
- Wilson, D. G., and G. B. Grayson. 1980. *Age-Related Differences in the Road Crossing Behavior of Adult Pedestrians*. Publication No. TR RL-L-933, Transportation and Road Research Laboratory, Crowthorne, UK.

Case Studies: Designing for All Users

6.1 Introduction

This chapter presents four case studies of project design processes that evaluate alternatives for improving the accommodation of all users (motorized and non-motorized) of a facility. In each case study, the roadways under design are primarily auto-dominated facilities, and the design process evaluates alternatives for balancing safety, LOS and QOS to all anticipated modes.

The four design case studies are abbreviated versions of case examples originally developed in other design guidance documents. To accommodate the style variations of the case studies, numbered headings extend only to second-level headings in this chapter. Case studies A and C are adapted with permission from *Designing Walkable Urban Thoroughfares: A Context Sensitive Approach* (ITE 2010a). The design process used in these examples is relatively simple and qualitative, but the cases provide effective examples of a thoughtful and comprehensive process for developing, evaluating and selecting solutions to design challenges. They employ a straightforward, high-level trade-off analysis for different design elements and goals. The design examples provide a general overview of the process to illustrate the five suggested stages of design in the ITE document. As summarized in this Guide, case studies A and C focus on the details of the evaluation and development of the actual design.

Case studies B and D are adapted with permission from *NCHRP Report 785: Performance-Based Analysis of Geometric Design of Highways and Streets* (Ray et al. 2014). The design process used in these examples represents a higher order of design analysis that is intended to help users apply the concepts, models and performance evaluation framework element presented in the NCHRP report. The original case studies are based on a variety of specific projects, amalgams of projects, or project considerations that are commonly found in practice. The key project elements evaluated are emphasized to support and promote the principles of performance-based analysis of geometric design. The examples selected for case studies B and D in this Guide involve designing projects for a mix of users in common scenarios potentially faced by design practitioners.

All the case study examples provide useful information to the design practitioner. They illustrate the range of qualitative and quantitative design analysis that can be applied to a multimodal design process addressing several different roadway classifications and contexts in low- and intermediate-speed environments. The formatting of headings and text within the case studies generally reflect the presentations used in the original documents. For readers' convenience, some minor stylistic edits have been made and exhibit numbering has been updated for consistency with the rest of this Guide.

6.2 Design Case Study A: Creating a Retail-Oriented Main Street

This design alternatives case study for creating a retail-oriented main street is taken from *Designing Walkable Urban Thoroughfares: A Context Sensitive Approach* (ITE 2010a). The project involves conversion of an existing four-lane collector street into a commercial-oriented street that supports typical community main street activities.

Although the design case study illustrates how a designer can evaluate design alternatives in a primarily qualitative manner, elements of quantitative analysis (e.g., employing more detailed quality, capacity and safety analysis procedures) could be integrated into the design concept evaluation process. Additional information about the specific context designations mentioned in the case study can be found in the original ITE document (ITE 2010a).

6.2.1 Design Objective

Convert an existing four-lane minor collector street into a commercial-oriented street that supports an adjacent mix of retail, restaurants and entertainment uses on the ground floor.

Stage 1: Review or develop an Area Transportation Plan.

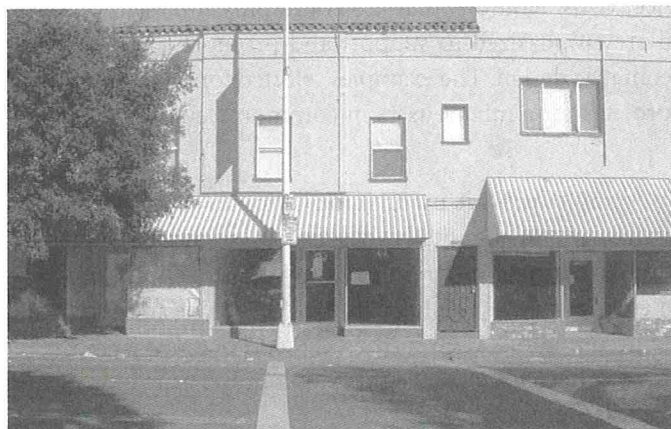
Review the area transportation plan(s) to determine how the subject thoroughfare relates to the overall network, types of modes served, functional classification, existing and future operational characteristics and so forth. Collect existing and projected data as necessary.

6.2.2 Existing Street Characteristics

The existing street is a four-lane, undivided collector street with the following characteristics (see Exhibits 6-1 and 6-2).

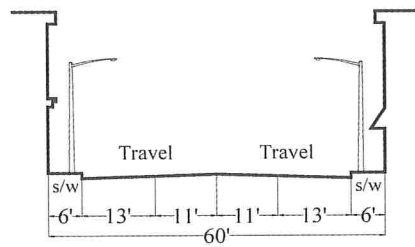
- Functional classification: minor collector;
- Right-of-way: 60 ft.;
- Four through-traffic lanes plus 6-ft. sidewalks on each side;
- On-street parking: none;
- Average daily traffic (ADT): 10,000–13,000 vehicles per day (VPD);
- Speed limit: 35 mph;
- Percent heavy vehicles: 2–3 percent;
- Intersection spacing: 600–700 ft.;

Exhibit 6-1. View of existing street.



Source: ITE (2010a)

Exhibit 6-2. Existing street cross section.



Source: ITE (2010a)

- Network pattern: grid;
- Center turn lane: none;
- Transit: low-frequency local route;
- Bicycle facilities: not a designated bike route;
- No landscaping; and
- Conventional street and safety lighting.

Stage 2: Understand community vision for context and thoroughfare.

6.2.3 Vision

An existing commercial street in a suburban area undergoing change to an urban center. Emphasizes an active street life that is to be achieved through the mix and intensity of land uses, site and architectural design, with an emphasis on pedestrian facilities and on-street parking.

Stage 3: Identify compatible thoroughfare types and context zones.

Existing context is identified by assessing the character and attributes of existing land uses such as building orientation to the street, building height, parking orientation, mix and density of uses and so forth. Future context is determined by interpreting the vision, goals and objectives for the area. Note: The thoroughfare type is selected based on the set of urban thoroughfare characteristics listed in Table 4.2 in *Designing Walkable Urban Thoroughfares* (ITE 2010a). For brevity, the table is not reproduced in this Guide.

- Existing context zone: C-3 (suburban area);
- Future context zone: C-5 (urban center); and
- Desired thoroughfare type: avenue.

Stage 4: Develop and test the initial thoroughfare design.

6.2.4 Desirable Design Elements

Desirable design elements (ranked based on vision):

- Lower target speed;
- On-street parking;
- Wide sidewalks;
- Street furniture and landscaping including benches and space for cafes, public space and so forth;
- Pedestrian-scaled lighting;
- Street trees;
- Bus stops with shelters;
- Transitions between main street and adjacent higher-volume segments;
- Mid-block crosswalks on long block sections; and
- Bicycle accommodations.

6.2.5 Factors to Consider/Potential Trade-Offs

Factors to consider/potential trade-offs are:

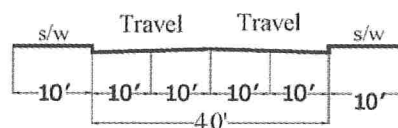
- Right-of-way constrained to 60 ft.;
- Maximized parking using angled versus parallel parking (although change to angled parking may increase accidents and delays);
- Reduction in the number of through lanes and vehicle capacity versus wider sidewalks and on-street parking;
- Accommodation of large vehicles versus narrowing lane width and smaller curb-return radii to reduce pedestrian crossings; and
- Accommodation of bicyclists versus width of other design elements.

6.2.6 Possible Alternative Solutions

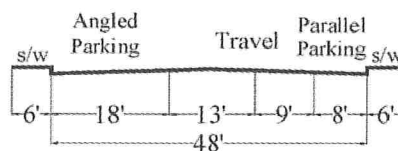
Possible alternative solutions (see Exhibit 6-3) are:

1. Emphasize vehicular capacity by retaining existing four-lane section with 10-ft.-wide travel lanes to allow 10-ft.-wide sidewalks;
2. Emphasize parking by providing angled parking on one side, parallel parking on the other side and narrowing the two remaining travel lanes;
3. Emphasize parking and wider sidewalks by providing parallel parking on both sides, two travel lanes and 12-ft.-wide sidewalks; or

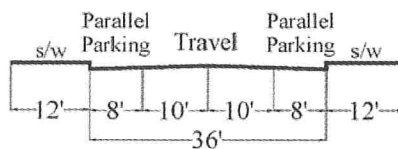
Exhibit 6-3. Alternative street cross sections.



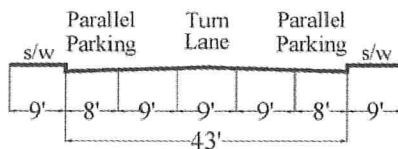
Alternative #1



Alternative #2



Alternative #3



Alternative #4

Source: ITE (2010a), Figure 6-12

4. Emphasize parking and vehicular capacity with parallel parking on both sides, 9-ft.-wide sidewalks, two travel lanes and a center turn lane.

In all cases, use a grid network to divert some traffic from project thoroughfare so a reduced number of traffic lanes will suffice. This approach may require operational or physical improvements to other streets. Traffic to be diverted will depend on travel patterns, context and design of other thoroughfares. Compare the benefits of the alternatives. Exhibit 6-4 demonstrates one way of showing such a comparison.

6.2.7 Selected Solution

This alternative:

- Maximizes sidewalk width;
- Provides moderate to good level of on-street parking;
- Balances street width with accommodation of larger vehicles and speed reduction;
- Allows for left-turn lanes at intersections by restricting parking; and
- Provides 10-ft. minimum travel lane width.

Stage 5: Develop a detailed thoroughfare design.

Exhibit 6-5 shows a rough schematic view of how the selected alternative might be designed.

6.2.8 Solution Design Features

Traveled Way:

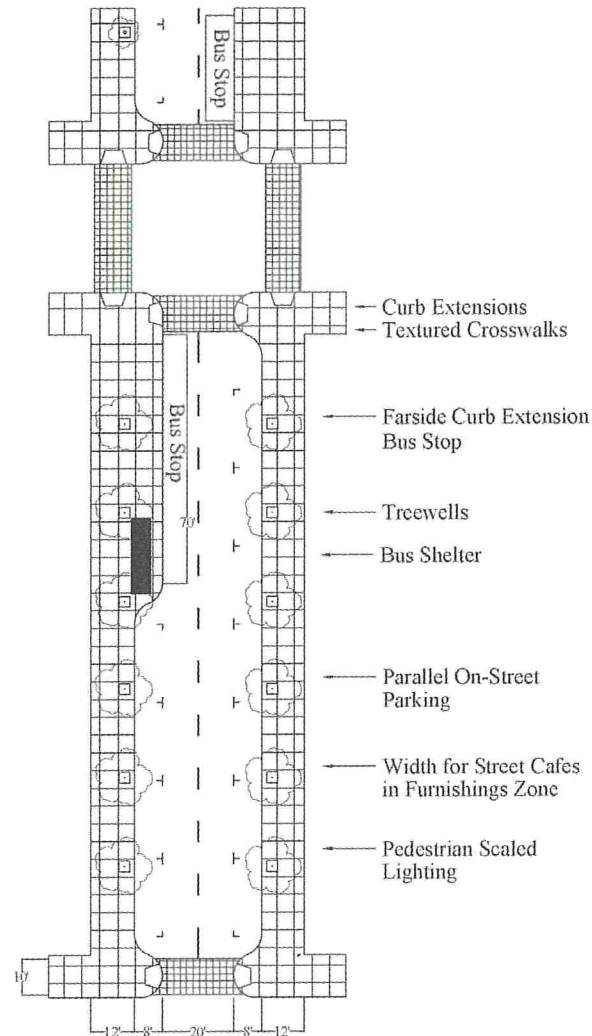
- Target speed: 25 mph;
- Traffic signals synchronized to target speed;
- Two 10-ft. travel lanes; and
- Two 8-ft. parallel parking lanes.

Exhibit 6-4. Relative comparison of alternative trade-offs.

Relative Comparison of Trade-Offs								
Alternative	Parking	Sidewalk Width	Vehicular Capacity	Large Vehicle Accommodation	Pedestrian Crossing Width	Left Turn Lanes	Bike Accommodation	Ped. Amenity Accommodation
Existing	--	--	++	++	--	--	--	--
1	--	++	++	--	--	-	--	+
2	++	--	-	+	++	++	--	-
3	+	++	-	++	++	-	--	+
4	+	-	+	--	+	++	--	++
Score (relative to other alternatives)								
++ Good (achieves objectives)								
+ Fair								
- Poor								
-- Fails to meet/achieve objectives								

Source: ITE (2010a)

Exhibit 6-5. Schematic plan view of Alternative 3.



Source: ITE (2010a)

Streetside:

- 12-ft. sidewalks;
- Pedestrian-scaled lighting;
- Street trees in tree wells;
- 6-ft. furnishings and edge zone;
- 6-ft. clear pedestrian throughway; and
- No frontage zone.

Intersections:

- Curb extensions to reduce pedestrian crossing distance unless left-turn lane is provided;
- High-visibility crosswalk markings;
- Safety lighting;
- Far-side bus stops with curb extension and shelters; and
- ADA compliance.

Parallel Thoroughfares (as needed):

- Directional signing;
- Operational adjustments or improvements; and
- Physical improvements.

6.3 Design Case Study B: Cascade Avenue

The design alternatives case study for Cascade Avenue is taken from *NCHRP Report 785: Performance-Based Analysis of Geometric Design of Highways and Streets* (Ray et al. 2014). This project involved reconstruction of an existing urban arterial with the goal of integrating new “complete streets” elements into the corridor project to better accommodate multiple modes and support improvements to community livability and increased economic activity.

This case study illustrates how the performance-based analysis suggested by *NCHRP Report 785* can be incorporated into the design concept development process. It also demonstrates the complicated nature of evaluating and interpreting results for several alternatives across multiple modes using a variety of performance measures. For a more detailed version of this case study that includes the report author’s notes, see *NCHRP Report 785*.

This project example illustrates how performance-based analysis can be integrated into reconstructing an existing auto-oriented urban arterial to incorporate complete street attributes with a focus on alternative street cross sections. In this project example, the project is initiated and championed by local business owners (i.e., local business improvement district) who would like to see the corridor revitalized in terms of the local economy and broader community livability.

The learning objectives of this project example include the following:

- Incorporate performance measures and decisions related to accommodating multiple modes;
- Illustrate trade-offs between modes considering measures beyond mobility; and
- Capture considerations and trade-offs within a constrained physical environment.

The broader project objectives (i.e., increase economic vitality and community livability) are connected to geometric design performance categories of QOS for multiple modes, safety, access, reliability and mobility.

6.3.1 Project Initiation

Project Context

The following summary of the project context sets the foundation for the remaining activities within the performance-based analysis framework. An important factor in the context of this project example is that the motivation for the project is being driven both by members of the local business community, who would like to see the corridor revitalized from an economic standpoint, and by the perspective of long-term livability for the surrounding community.

The local business community lobbied city staff and decision makers to study and implement design solutions to Cascade Avenue. The intended project outcome is to make it a more comfortable, safe and attractive urban street for transit riders, pedestrians and bicyclists. Cascade Avenue is an urban arterial providing a north-south connection between the downtown district and a university campus approximately 2 miles north of downtown. It is currently a four-lane undivided arterial with on-street parallel parking and intermittent transit stops. Under the existing condition, there are no bicycle lanes and sidewalks are curb-tight (i.e., no landscape buffer exists between the sidewalk and roadway).

The AADT volume for Cascade Avenue is 22,000 VPD. It is a key arterial for three different fixed transit routes serving approximately 45 percent of the transit riders traveling within the city.

Despite the lack of bicycle facilities on Cascade Avenue, it is already a frequently used route by bicyclists traveling between downtown and the university campus, as it is the most direct route between those two origins-destinations. The posted speed on Cascade Avenue is 35 mph. Local law enforcement has a difficult time enforcing the posted speed during off-peak periods when traffic is relatively low. The higher speeds in off-peak travel periods make Cascade Avenue less attractive to pedestrians and bicyclists.

The local business community would like Cascade Avenue to become a more well-rounded city street. They would like people in the surrounding communities to see and use it as a place to spend time, visit shops, linger at cafes and restaurants, as well as use it to travel within the city.

The business community's overarching motivation for the project is to revitalize Cascade Avenue and the surrounding area economically. They see improvements to Cascade Avenue from an urban design and transportation perspective as critical to their mission. The city agreed to study the street to identify and evaluate a range of potential configurations to better serve multiple modes and create a more complete urban street environment.

This project example documents the preliminary design development and evaluation of alternative street cross sections. The primary condition requested by local business owners is to keep the potential solutions on Cascade Avenue within the existing 82-ft.-wide right-of-way.

The business community is open to removing the existing on-street parking as a means to provide more space for other modes or uses. They are also in the process of gaining support from a broad base of local business owners to form a local improvement district (LID) to help fund the project.

6.3.2 Intended Project Outcomes

The project example summarizes the key information related to stakeholders the project is intended to serve, what the project is intended to achieve (i.e., intended project outcome), the applicable project performance category (or categories), and the applicable performance measures.

In this project example, the project purpose is to enhance the multimodal characteristics of Cascade Avenue in support of the local business improvement district that would like to have more pedestrian activity along the corridor as a means for revitalizing the surrounding community. There are no direct geometric performance measures for evaluating how well a project alternative will revitalize or facilitate economic or community growth. However, there are indirect geometric performance measures contributing to characteristics that would support economic and/or community revitalization (e.g., QOS for pedestrians, bicyclists and transit riders). In this project example, safety, mobility, QOS, accessibility and reliability are the geometric performance categories contributing to the broader goal of improving economic vitality along the corridor.

The local business community is the champion for the project. They are the catalyst for identifying and implementing a project on Cascade Avenue with the purpose of revitalizing the street and surrounding areas from an economic and livability perspective. The primary target audience is the business community stakeholders who would like to see transit riders, pedestrians and bicyclists better served by Cascade Avenue. As a result, transit riders, pedestrians and bicyclists are key road users served by the project. Secondary target audiences include local residents and existing motorists. The project will need to balance the impacts on existing

automobile and transit service. The key agency stakeholders are the city and local transit agency. The city has jurisdictional responsibility over Cascade Avenue. Therefore, it will be responsible for capital improvements, maintenance and operations of the street. The local transit agency currently has three of its major fixed-route bus routes using Cascade Avenue to serve a large portion of its ridership.

The intent of the study is to improve the road user experience and provide access for road users not previously served while enhancing the economic vitality and activity of the street. The performance categories selected are QOS, safety, accessibility, reliability and mobility.

The performance measures to be used to evaluate alternative roadway cross sections are:

- QOS (MMLOS from the HCM (TRB 2010));
- Safety (crash frequency and number and management of conflict points);
- Accessibility (type and presence of facilities and transit service characteristics);
- Mobility (average travel time); and
- Reliability (consistency in travel time).

These performance measures do not directly measure economic vitality for an area or the potential for economic vitality. However, they are connected to geometric characteristics and reflect characteristics influencing different road users' quality of experience. For example, a better MMLOS grade for the pedestrian mode corresponds to roadway geometric characteristics more likely to create an attractive environment in which pedestrians feel safe and comfortable.

This helps achieve the business community's goal of transforming Cascade Avenue into a city street where people want to shop, dine, and generally spend time. Similar parallels can be drawn for the other performance measures listed.

6.3.3 Concept Development

Geometric Influences

Roadway cross-sectional elements were selected as the primary geometric elements likely to influence the performance measures associated with:

- Lane width;
- Number of automobile through lanes;
- Bicycle facility presence and type (e.g., bicycle lanes, buffered bicycle lanes);
- Sidewalk width;
- Presence and width of landscaped buffer between sidewalk and travel lanes;
- Presence and type of on-street parking (e.g., parallel parking, angled parking);
- Bus-only lanes; and
- Central roadway median.

The potential solutions explore different combinations of cross-section characteristics and create a range of alternatives reflecting the trade-offs inherent in trying to serve different travel modes within a constrained right-of-way.

6.3.4 Potential Solutions

The primary constraint and challenge in developing solutions for Cascade Avenue is serving the range of existing and desired road users within the existing right-of-way. Automobiles are currently given the majority of space on Cascade Avenue; therefore, additional alternatives developed for Cascade Avenue are oriented toward one or more combinations of better serving

transit riders, pedestrians, and bicyclists. The four basic alternatives (including the existing condition) are:

- Basic Alternative 1: Existing cross section oriented toward serving automobiles;
- Basic Alternative 2: Transit-oriented cross section;
- Basic Alternative 3: Bicycle- and pedestrian-oriented cross section; and
- Basic Alternative 4: Hybrid of transit, bicycle, and pedestrian features.

Alternative 1 will serve as a common baseline for comparison across alternatives; it is the existing roadway that prioritizes space for automobiles. Alternative 2 focuses on serving transit vehicles and riders. The roadway features within Alternative 2 include elements such as transit-only lanes. Alternative 3 is oriented toward bicycle and pedestrian modes and includes features such as buffered bicycle lanes. Alternative 4 is a hybrid of alternatives 2 and 3. It strives to balance the needs of transit riders, bicyclists, and pedestrians.

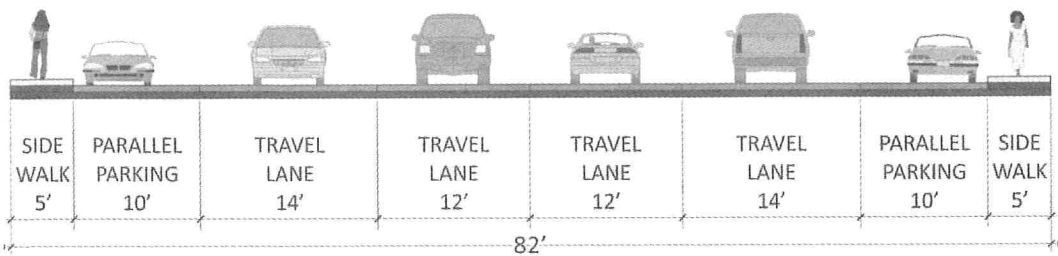
- **Resources used to develop solutions.** The project team used the *Urban Street Design Guide* (NACTO 2013) as a resource for developing alternative cross sections. The team also used NACTO's *Urban Bikeway Design Guide* (NACTO 2014) and AASHTO's *Guide for the Development of Bicycle Facilities*, 4th Ed. (AASHTO 2014b) in identifying and developing alternatives. They used these guidance documents in combination with the city's local design guides and standards. The resources were particularly helpful in providing visuals, examples, and alternative approaches for addressing the challenge of serving multiple travel modes. This project example focuses on documenting the development, analysis, and selection of a new, basic cross section for Cascade Avenue. There is valuable information in these reference materials regarding design and operational strategies for managing conflicts between modes at intersections and within the transition areas influencing how well an overall street corridor serves road users.
- **Solution development.** Each alternative cross section has a modal emphasis in contrast to the existing auto-oriented cross section. The cross-section alternatives were developed to be reasonable representations of a type of alternative. This means some design details (such as curb type) will be determined in later stages of project development.

A common element among the alternatives is the lack of on-street parking. The local business community expressed interest in increasing pedestrian activity on the street and therefore the desire to focus on solutions providing more space for that activity. This approach is consistent with the broader city's goals and policies to focus on projects serving person-trips rather than auto-only trips. This translates to creating more space for modes other than autos. The primary concern related to eliminating on-street parking on Cascade Avenue was that vehicles would use on-street parking in adjacent residential areas. The city is addressing this concern as part of a broader citywide parking management plan encompassing the Cascade Avenue area as well as the downtown district and the area surrounding the university.

Other trade-offs considered by the project team while developing and identifying the specific characteristics within each cross section included allocating lanes for specific modes. For example, providing a transit-only lane has the ability to improve mobility and reliability for transit riders by reducing the average travel time along the corridor for transit riders. This option also provides more predictable operating conditions for transit vehicles in peak traffic conditions. Allocating space to transit vehicles negatively impacts mobility (and potentially reliability) for automobiles, however, because they are reduced to one lane in each direction of travel instead of the existing two lanes. Similar trade-offs were considered related to providing bicycle lanes and wider sidewalks for pedestrians.

Another characteristic reflected in two of the alternatives is adding a central landscaped median that would transform Cascade Avenue to a divided facility. There are documented safety benefits for autos and pedestrians in having a median. A median also provides space

Exhibit 6-6. Cross section of existing roadway.



to implement landscaping to help improve the aesthetics of the corridor. As will be seen in Alternative 3, the project team also considered changes that would provide additional designated space for pedestrians and bicyclists and create a buffer between pedestrians and bicyclists and moving vehicles. The intent of these features is to decrease the likelihood of crashes and improve the overall experience of traveling and spending time on Cascade Avenue.

6.3.5 Primary Alternatives for Evaluation

Using the resources and considerations previously described in brief, the project team arrived at the following alternatives for evaluation:

- Alternative 1 (Existing, Auto Oriented): Four-lane undivided roadway with on-street parallel parking on both sides of the street (see Exhibit 6-6);
- Alternative 2 (Transit Oriented): Four-lane divided roadway with transit-only lanes and increased sidewalk widths (see Exhibit 6-7);
- Alternative 3 (Bicycle and Pedestrian Oriented): Two-lane divided roadway with a buffered bicycle lane, landscaped buffer, wider sidewalks, and shared auto-transit lane (see Exhibit 6-8); and
- Alternative 4 (Hybrid of Transit, Bicycle and Pedestrian Alternatives): Four-lane undivided roadway with transit-only lanes, bicycle lanes, and a wider sidewalk (see Exhibit 6-9).

- The exhibits illustrate common elements among the alternatives. For example, the alternatives:
- Fall within the existing 82-ft. of right-of-way width and, therefore, do not require additional right-of-way;
 - Require changing the existing curb locations and, therefore, revising stormwater management and drainage along the corridor;

Exhibit 6-7. Transit-oriented roadway cross section.

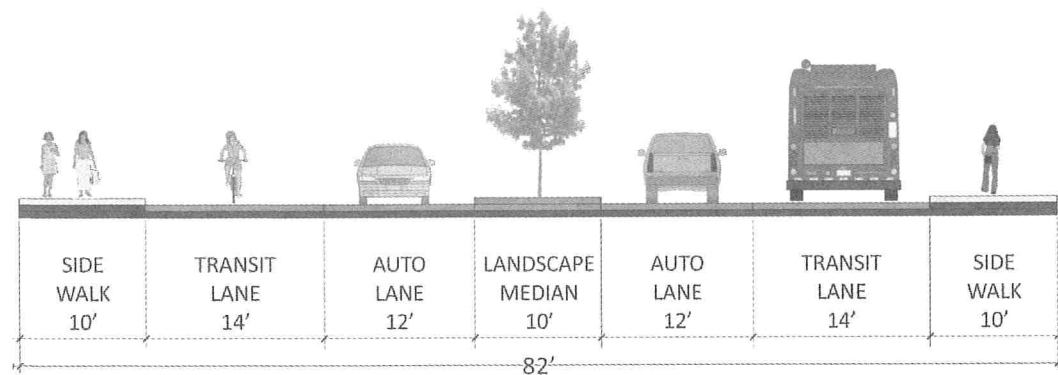
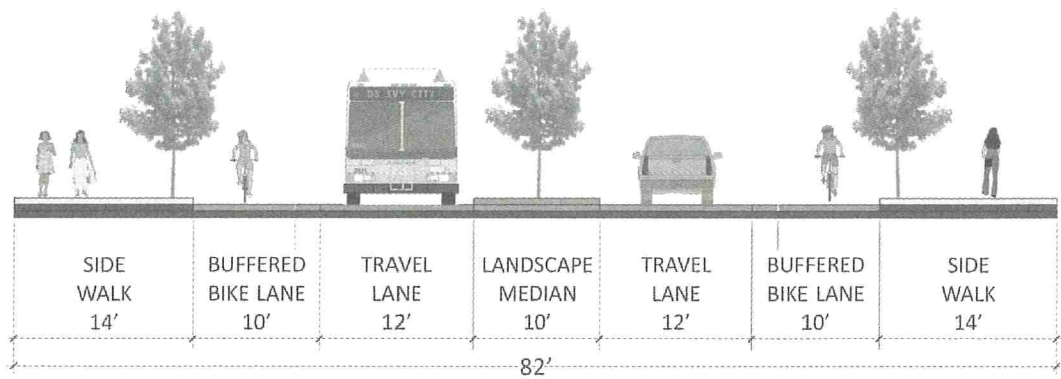


Exhibit 6-8. Bicycle- and pedestrian-oriented roadway cross section.



- Reduce the capacity for automobiles from two lanes in each direction to one lane in each direction;
- Remove on-street parking (as discussed previously); and
- Increase sidewalk width for pedestrians.

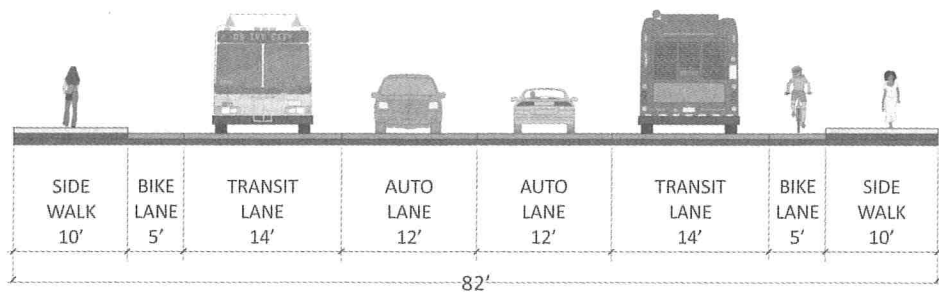
The differentiating factors across the alternatives that influence their performance include the amount of space designated for bicyclists, presence of a central median, the presence of a physical buffer for pedestrians and bicyclists from motorized vehicles, and the type of space allocated for transit vehicles.

Additional critical issues that are not directly captured in the exhibits but that will need to be considered prior to selecting an alternative for implementation include the following:

- Logistics (e.g., allocating designated zones) of truck loading and unloading for the businesses along Cascade Avenue;
- Definition of transition areas on approach to intersections or major driveways where vehicle turning movements will occur; these conflict areas will need to be managed particularly within alternatives providing transit-only and/or bicycle lanes; and
- Revisiting, confirmation, and possibly modification of intersection control, lane configurations, and/or signal timing (if a signal is present) to better align with the selected cross section.

For example, if Alternative 2, the transit-oriented cross section, is selected, the city may want to implement transit signal priority to help maintain consistent and reliable transit service along the corridor. These additional considerations are not addressed within this project example but are considered in the broader context of implementing the selected cross-sectional alternative.

Exhibit 6-9. Hybrid of transit, pedestrian and bicycle alternatives.



6.3.6 Evaluation and Selection

The performance categories evaluated for this project focus on the following:

- Safety, as defined by crash frequency, crash severity and conflict points;
- Mobility, as defined by average travel time;
- Reliability, as defined by variation in travel time;
- Accessibility, as defined by type and facility presence and transit service characteristics; and
- QOS, as defined by MMLOS.

To the extent feasible, the project team estimated the performance of each alternative quantitatively. However, in some cases, due to the state of the research and practice, a qualitative assessment was necessary. Exhibit 6-10 summarizes the resources used to calculate the performance of each alternative.

The *NCHRP Report 785* project team faced several challenges in being able to assess each alternative quantitatively across the full range of selected categories and associated performance measures. The primary challenge reflected gaps in the available research findings. For example, these gaps impeded efforts to quantify the performance of all of the innovative street cross sections being considered for Cascade Avenue. This section provides more detailed descriptions of how each resource can be used to estimate the performance measures identified under the “Intended Project Outcomes.” The descriptions include instances when a qualitative assessment was necessary.

- **Safety.** The methodologies and information in AASHTO’s HSM can be used to estimate the predicted safety performance for roadway cross sections of urban/suburban arterials. The HSM addresses cross sections ranging from two-lane undivided to five lanes (a five-lane cross section has two lanes in each direction with a two-way center turn lane). Therefore, the HSM can be used to estimate the long-term annual safety performance of Cascade Avenue under existing conditions. However, the remaining alternatives include cross-sectional features that cannot be evaluated using the HSM or another known resource:
 - The transit lanes present in Alternatives 2 and 4,
 - The buffered bicycle lane present in Alternative 3, and
 - The traditional bicycle lane in Alternative 4.
 Therefore, the relative safety performance of these alternatives was considered qualitatively based on their abilities to separate conflicting modes and provide additional and/or protected space for vulnerable users (i.e., pedestrians and bicyclists).
- **Mobility.** The project team used a software program to implement HCM 2010 methodologies (TRB 2010) and estimate the average travel time from one end of Cascade Avenue to the other. The average travel time was estimated for the morning, midday, and evening weekday

Exhibit 6-10. Summary of resources for performance evaluation.

Alternative	Safety	Mobility	Reliability	Accessibility	QOS
1: Existing Condition	HSM, Chapter 12	HCM 2010	HCM 2010	Qualitative Assessment	HCM 2010
2: Transit Oriented	HSM, Chapter 12 Principles	HCM 2010	HCM 2010	Qualitative Assessment	HCM 2010
3: Bicycle and Pedestrian Oriented	HSM, Chapter 12 Principles	HCM 2010	HCM 2010	Qualitative Assessment	HCM 2010
4: Hybrid of Transit, Bicycle, & Pedestrian	HSM, Chapter 12 Principles	HCM 2010	HCM 2010	Qualitative Assessment	HCM 2010

Resource references: HSM (AASHTO 2010), HCM 2010 (TRB 2010)

Source: Ray et al. (2014)

periods, as well as the Saturday midday peak period. The intent of including multiple periods was to obtain a sense of the range of travel time during low-, mid-, and high-traffic volume periods. The analysis focused on average travel time for motorists and transit vehicles (and, therefore, transit riders).

- **Reliability.** Research is ongoing within the transportation profession to develop performance measures and a means to strengthen the connection between reliability and geometric design decisions. In the context of urban arterials, measuring the variation in travel time is the best means for estimating relative consistency for motorists and transit riders on Cascade Avenue. To estimate the potential variation in travel time, the project team simulated traffic operations along the corridor for different periods of the day to reflect different traffic volume demands and introduced different unanticipated events (e.g., partial or full lane closure due to a crash or truck loading/unloading) to estimate the relative consistency in travel time for each alternative. The analysis focused on the variation in travel time for auto and transit vehicles. As will be seen in the results discussed later, providing a transit-only lane can notably help improve reliability for transit vehicles and riders. Results only speak to the reliability of the transit routes while they are traveling on Cascade Avenue; events may occur prior to or after the routes depart Cascade Avenue that negatively impact their overall reliability.
- **Accessibility.** The project team evaluated access qualitatively, giving it an assessment of low, moderate or high depending on the presence of facilities for specific modes and the transit service characteristics reflected in each alternative. Within this project context, additional access to the corridor for pedestrians, bicyclists, and transit riders was considered a positive performance characteristic given the overarching goal of the project to increase economic vitality of the corridor through increased pedestrian activity or person-trips.
- **QOS.** MMLOS was calculated using the methodology presented in the HCM 2010 (TRB 2010). The methodology produces a letter grade (A through F) to indicate the quality of the travel experience from specific road users' perspectives. Therefore, it is possible for the same alternative to produce a LOS C for bicyclists and LOS B for pedestrians. In other words, the methodology reflects that one street cross section can result in different qualities of experience depending on whether a person is walking, biking, taking transit or driving an automobile. It is a useful methodology, particularly in combination with the HSM, because MMLOS captures some of the benefits from project elements the HSM cannot, such as bicycle lanes.

The results of the performance analysis are summarized in Exhibit 6-11. The results for the safety and access evaluations are categorized as low, moderate or high. In the context of this project, high performance in those two categories is desirable. High safety performance means, in a qualitative assessment, there is a lower likelihood of crashes and/or severe crashes due to attributes such as separate designated space for vulnerable modes, physical separation of vulnerable modes from motorized vehicles, and other similar attributes.

Exhibit 6-11 demonstrates that it can be a complicated exercise to evaluate and interpret results from the evaluation of several alternatives across multiple modes using a variety of performance measures. Key themes the project team identified from the performance evaluation results included the following:

- **Safety.** Alternatives 2 and 3 are expected to have better safety performance compared to other alternatives. This is attributable to the presence of the central median. The median separates vehicles moving in the opposite direction and provides a pedestrian refuge for pedestrian crossings at intersections and mid-block. These alternatives also include separate facilities designated for auto, transit and bicycles. Furthermore, Alternative 3 includes additional buffering for pedestrians and bicyclists from motorized traffic. As noted previously, if Alternative 2 or 3 is selected (or if Alternative 4 is selected), the project team will need to spend time designing transition areas to transition from the street cross section to intersections where vehicle turn movements will need to occur. Within Alternative 3, the team will also need to consider and develop an approach

Exhibit 6-11. Performance evaluation results.

Alternative	Safety	Mobility: Average Travel Time (min.)	Reliability: Variation in Travel Time (min.)	Quality of Service: Accessibility MMLOS	
<i>1 – Existing Condition</i>					
Pedestrian	Low	—	—	Low	D
Bicycle	Low	—	—	Low	F
Transit	Low	4.43	3.68 to 5.26	Moderate	D
Auto	Low	2.67	2.42 to 3.17	High	A
<i>2 – Transit Oriented</i>					
Pedestrian	High	—	—	Moderate	C
Bicycle	Moderate	—	—	Moderate	E
Transit	High	4.40	3.68 to 4.76	High	B
Auto	High	3.43	3.35 to 3.60	Low	C
<i>3 – Bicycle and Pedestrian Oriented</i>					
Pedestrian	High	—	—	High	B
Bicycle	High	—	—	High	C
Transit	High	4.80	3.97 to 6.00	Moderate	D
Auto	High	4.80	3.80 to 6.10	Low	D
<i>4 – Hybrid of Transit, Bicycle and Pedestrian</i>					
Pedestrian	Low	—	—	Moderate	C
Bicycle	Moderate	—	—	Moderate	D
Transit	Moderate	4.38	3.65 to 4.78	High	B
Auto	Low	3.45	3.32 to 3.56	Low	C

The exhibit summarizes results for the Saturday midday peak period. Similar summaries were prepared for the weekday evening and morning periods.

— indicates not applicable.

Source: Ray et al. (2014)

for managing conflicts between transit vehicles and bicyclists on approach to transit stops. This may include strategies such as moving the transit stop to a platform away from the sidewalk and having the bicycle lane pass between the platform and the sidewalk. Alternatives 1 and 4 have the lowest expected safety performance. This is attributed to the lack of a central median and, in the case of Alternative 1, the lack of separate facilities for bicyclists and transit vehicles.

- **Mobility.** Alternative 1 is expected to have the highest mobility (i.e., lowest average travel time) for motorists on Cascade Avenue, which is attributed to the four-lane cross section. Alternatives 2 and 4 are the next two alternatives with higher mobility for motorists and transit vehicles. Each of these alternatives includes a transit and auto lane in each direction and, therefore, has similar mobility results for those modes. The average travel time reflected in alternatives 2 and 4 is closer to the posted speed limit on Cascade Avenue of 35 mph, which is desirable with respect to safety (i.e., it provides more time for motorists to react to roadway conditions and is more likely to result in less severe crashes in the event one occurs) and creating a more comfortable environment for pedestrians and bicyclists.
- **Reliability.** Alternatives 2 and 4 have the highest reliability (i.e., lowest variation in travel time) for transit riders and motorists. While these two alternatives do not have the highest mobility for motorists, they do create moderately more consistent travel times. Increased reliability is achieved primarily by the transit lanes included within the alternatives. Transit lanes prevent

motorists from being stuck behind a transit vehicle loading and unloading passengers. The increased reliability is also attributable to removing the on-street parking present in Alternative 1. Alternative 3 has the lowest reliability for transit riders and motorists. This is because transit vehicles and motorists are sharing a single travel lane in each direction; therefore, transit stops, truck loading and unloading maneuvers, and incidents (and incident management) directly affect the space both modes need for travel. This creates the greater variation in travel time.

- **Accessibility.** Alternatives 2, 3 and 4 provide similar levels of access for pedestrians, transit riders, bicyclists, and motorists. Within Alternatives 2, 3 and 4, access (with respect to being able to travel on Cascade Avenue and gain access to the businesses along it) ranges from moderate to high for pedestrians, transit riders and bicyclists because of the presence of facilities for those modes. Within those same alternatives, access for motorists is evaluated as low. This is primarily because on-street parking is not included in alternatives 2, 3 or 4.
- **QOS.** Alternative 3 provides the highest QOS for pedestrian and bicycle modes. The high QOS for pedestrians is attributable to the wider sidewalks, landscaping buffer and additional separation from motorized vehicles gained from the adjacent buffered bicycle lane. For bicyclists, the higher QOS is attributable to eliminating on-street parking, providing a designated bicycle lane and including a wider width for the buffered bicycle lane. Alternatives 2 and 4 provide the best QOS for transit riders, which is primarily attributed to the operational benefits of the transit lanes (e.g., better service characteristics). This is in combination with the pedestrian improvements included in those alternatives. Motorists' QOS is highest in Alternative 1 because of the higher mobility and relatively few times motorists would need to stop. Motorists are expected to experience moderate QOS within alternatives 2 and 4. This is likely attributed to separating automobiles and transit vehicles to help manage the number of times motorists would need to stop while traveling the corridor.

Given these considerations purely based on performance evaluation results, the project team and broader stakeholders felt Alternatives 2 and 3 had performance characteristics best reflecting the attributes they desired for Cascade Avenue.

To evaluate financial feasibility, the project team developed cost estimates for each alternative. The cost estimates considered critical characteristics such as the costs of curb relocations, modifications needed to stormwater drainage and management, new pavement markings, revisions to signing, modifications to transit stop locations and configurations, improved illumination, and landscaping and other similar costs associated with the unique characteristics of each alternative. Exhibit 6-12 summarizes the cost estimates for the alternatives. The significant elements influencing cost include modifying the stormwater drainage, adding a median, landscaping, changing transit stop locations and configurations, and pavement rehabilitation.

Many of these attributes are present within Alternatives 2, 3 and 4 to varying degrees. Alternatives 2 and 3 are higher in cost than Alternative 4 because of the median and additional landscaping that they include.

The *NCHRP Report 785* project team did not estimate a benefit/cost ratio or calculate a cost-effectiveness factor for the alternatives. To be able to calculate a benefit/cost ratio or

Exhibit 6-12. Cost estimates.

Alternative	Cost per Mile
1: Existing Condition	\$0
2: Transit Oriented	\$1.4 million
3: Bicycle and Pedestrian Oriented	\$1.6 million
4: Hybrid of Transit, Bicycle and Pedestrian	\$1.0 million

Source: Ray et al. (2014)

cost-effectiveness factor, simplifying assumptions would be needed, and the city and project stakeholders did not want to oversimplify or omit performance measures they felt to be critical in selecting an alternative for Cascade Avenue. The city used the project cost information in combination with the performance evaluation results and understanding of the project context to reach consensus with project stakeholders on a preferred alternative.

6.3.7 Selected Alternative

The city and project stakeholders selected Alternative 2 as the preferred alternative. Alternative 2 provides improved safety, reliability, access and QOS for transit riders, pedestrians and bicyclists. Within this alternative, the bicycle QOS is the least improved relative to transit riders and pedestrians' anticipated experience.

Within Alternative 2, bicyclists will need to share the transit lane with transit vehicles. This is an improvement over existing conditions because of the lower number of transit vehicles relative to automobiles and the width of the transit vehicle lane. The city felt most comfortable with the performance of Alternative 2. This is primarily because of the improvement in safety across modes and the preservation of reasonable mobility and reliability for motorists and transit vehicles. Cascade Avenue is a critical corridor for transit service within the city. There are limited parallel alternative routes for motorists to use in place of Cascade Avenue that are not through residential areas. For those reasons, it was of high importance to the city to maintain a reasonable degree of mobility and reliability for motorists and transit, while better serving other modes.

The local business community that initiated the Cascade Avenue improvements preferred Alternative 3 and Alternative 2 as their secondary selection. Attributes from Alternative 3 that the city plans to integrate into Alternative 2 to address the business community's interests include adding landscaping along the sidewalks by using tree wells or other landscaping areas spaced at regular intervals. Attributes and characteristics to better serve bicyclists included elements such as bicycle corrals for easy parking in front of businesses, wayfinding signs for bicyclists, and signs and pavement markings to communicate to bicyclists and transit riders that bicyclists are permitted and encouraged to use the transit lane for travel.

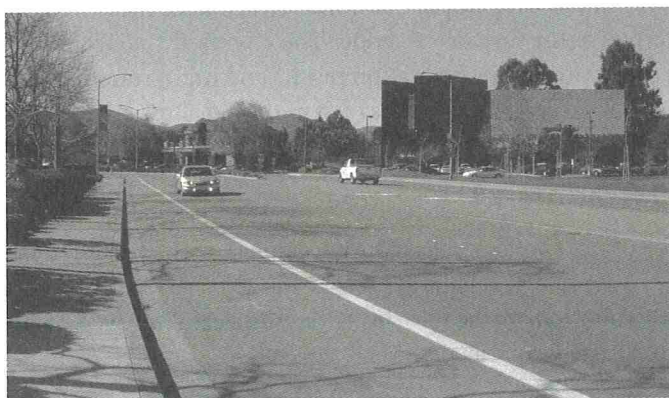
6.4 Design Case Study C: High-Capacity Thoroughfare in Urbanizing Area

This design alternatives case study is for creating a high-traffic capacity arterial roadway that also buffers adjacent users and land use from the traffic impact to the greatest extent possible. The original case study appears in *Designing Walkable Urban Thoroughfares: A Context Sensitive Approach* (ITE 2010a).

Although the case study illustrates how a designer can evaluate design alternatives in a primarily qualitative manner, elements of quantitative analysis (e.g., employing more detailed quality, capacity and safety analysis procedures) also could be integrated into the design concept evaluation process. The context designations are the same as those used in Design Case Study A. Additional details about the guidance and support information used to develop the case study can be found in the original ITE document (ITE 2010a).

6.4.1 Design Objective

Design a thoroughfare in a newly urbanized area that accommodates high levels of traffic and buffers adjacent land uses from traffic impacts.

Exhibit 6-13. View of existing street.

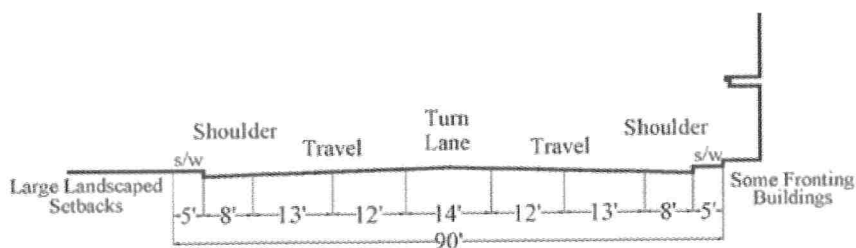
Source: ITE (2010a)

Stage 1: Review or develop an Area Transportation Plan.

6.4.2 Existing Street Characteristics (see Exhibits 6-13 and 6-14)

Existing street is a five-lane undivided arterial street with the following characteristics:

- Functional classification: minor arterial;
- Right of way: 90 ft.;
- Four through-traffic lanes plus center turn lane, median;
- On-street parking: none;
- Existing ADT: 25,000–30,000 VPD;
- Projected ADT: 45,000 VPD;
- Speed limit: 40 mph;
- Percent heavy vehicles: 4–5 percent;
- Intersection spacing: 600–700 ft., with many driveways;
- Network pattern: suburban curvilinear; few alternative parallel routes;
- Center turn lane: TWLTL with turn bays at intersections;
- Transit: moderate-frequency regional and local routes;
- Bicycle facilities: designated bicycle route with 8-ft.-wide paved shoulders on both sides;
- Narrow attached sidewalks (5 ft.) on both sides;
- No landscaping within right-of-way; and
- Conventional street and safety lighting.

Exhibit 6-14. Existing street cross section.

Source: ITE (2010a)

Stage 2: Understand community vision for context and thoroughfare.

6.4.3 Vision

Area plans envision a mix of high-density housing, retail centers and low-intensity commercial uses fronting the street. Because the roadway accommodates high levels of through traffic, access control is desired. The roadway is currently a bicycle route with bicyclists using the paved shoulder, but bicycle lanes are desired to close gaps in the bicycle system. Adjacent properties provide off-street parking, but some fronting residential and commercial uses would benefit from on-street parking. The area will generate pedestrians who desire buffering from adjacent traffic.

The area plan calls for a boulevard design including an alternative for a multiway boulevard with fronting access lanes to provide on-street parking and buffer proposed mixed use development with ground floor retail and housing above.

Stage 3: Identify compatible thoroughfare types and context zones.

- Existing context zone: C-3;
- Future context zone: C-5; and
- Thoroughfare type: boulevard.

Stage 4: Develop and test the initial thoroughfare design.

6.4.4 Desirable Design Elements

Desirable design elements (prioritized by vision) are:

- Lower target speed (35 mph);
- Emphasis on vehicular capacity;
- Access management with landscaped median;
- Bicycle lanes;
- Streetside buffered from traffic;
- Street trees;
- Bus stops with shelters;
- Increased crossing opportunities at signalized intersections;
- Pockets of on-street parking adjacent to fronting commercial or mixed use development; and
- Multiway boulevard design adjacent to mixed use development.

6.4.5 Factors to Consider/Potential Trade-Offs

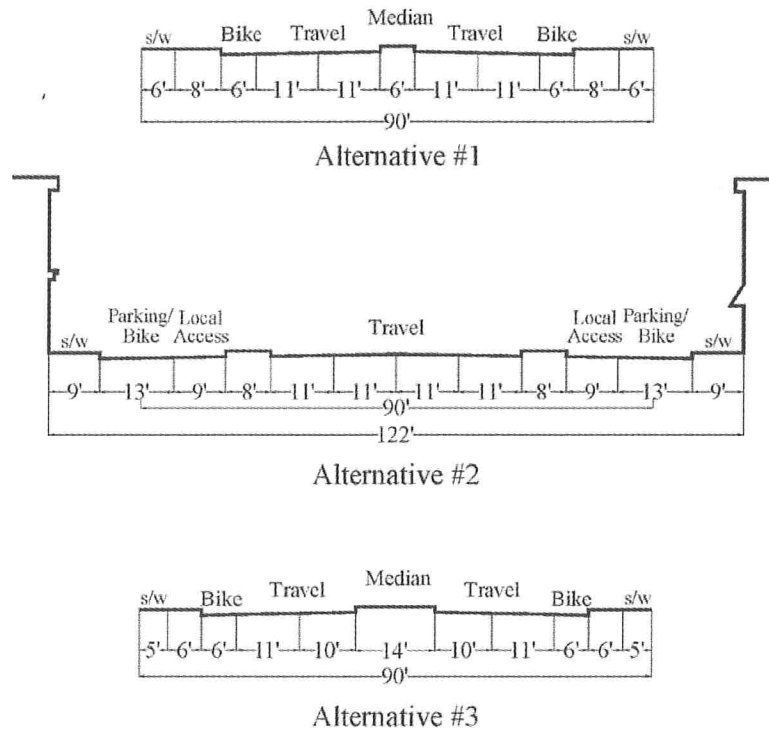
Factors to consider/potential trade-offs include:

- Effective width for streetside buffer versus width requirements for elements in traveled way;
- Accommodation of wider than minimum sidewalks, particularly in commercial areas;
- Provision of on-street parking in select segments versus other design elements;
- Intersections spaced to optimize traffic flow versus need for increased crossing opportunities;
- Accommodation of large vehicles, particularly turning at intersections;
- Right-of-way requirements for implementing a multiway boulevard; and
- Efficient intersection operations with multiway boulevard.

6.4.6 Possible Alternative Solutions

Possible alternative solutions (see Exhibit 6-15) are:

- Alternative 1: Emphasize streetside buffering and provision of bike lanes; provide minimal width median for access control and narrower travel lanes.

Exhibit 6-15. Alternative street cross sections.

Source: ITE (2010a)

- Alternative 2: Implement multiway boulevard with local access streets that provide on-street parking and shared bicycle/vehicle environment. This allows a wider streetside area and removes bicycles from higher-speed roadway. This configuration requires 15 ft. of right-of-way acquisition on each side of roadway, or adjacent development dedicates streetside and on-street parking lane.
- Alternative 3: Emphasize landscaped median and bicycle lanes by narrowing streetside. Provides minimal sidewalk width and reduced buffer area.

In all cases use grid network to divert some traffic from project thoroughfare. This may require operational or physical improvements to other streets. Traffic to be diverted will depend on travel patterns, context and design of other thoroughfares.

Compare benefits of the three alternatives. Exhibit 6-16 demonstrates one way of showing such a comparison.

6.4.7 Selected Alternative

Alternative 2 was selected as the solution. This alternative:

- Provides desirable design features, including the desire for a multiway boulevard;
- Is feasible to implement in newly urbanizing area with redevelopment opportunities;
- Requires either dedication or right-of-way acquisition, but could be implemented in phases; and
- Requires special design of intersections to maintain efficient operations.

Stage 5: Develop a detailed thoroughfare design.

Exhibits 6-17 through 6-19 show a schematic view of how the selected alternative might be designed.

Exhibit 6-16. Relative comparison of alternative trade-offs.

Alternative	Parking	Sidewalk Width	Roadside Buffer	Vehicular Capacity	Large Vehicle Accommodation	Pedestrian Crossing Width	Left Turn Lanes	Landscaped Median	Bike Lanes	Speed Reduction	Right-of-way
Existing	--	--	--	++	++	--	++	--	+	--	++
1	--	-	++	+	++	-	-	-	++	+	++
2	++	++	++	++	++	++	-	++	++	+	--
3	--	--	+	+	+	+	++	++	++	++	++

Score (relative to other alternatives)

++ Good (achieves objectives)

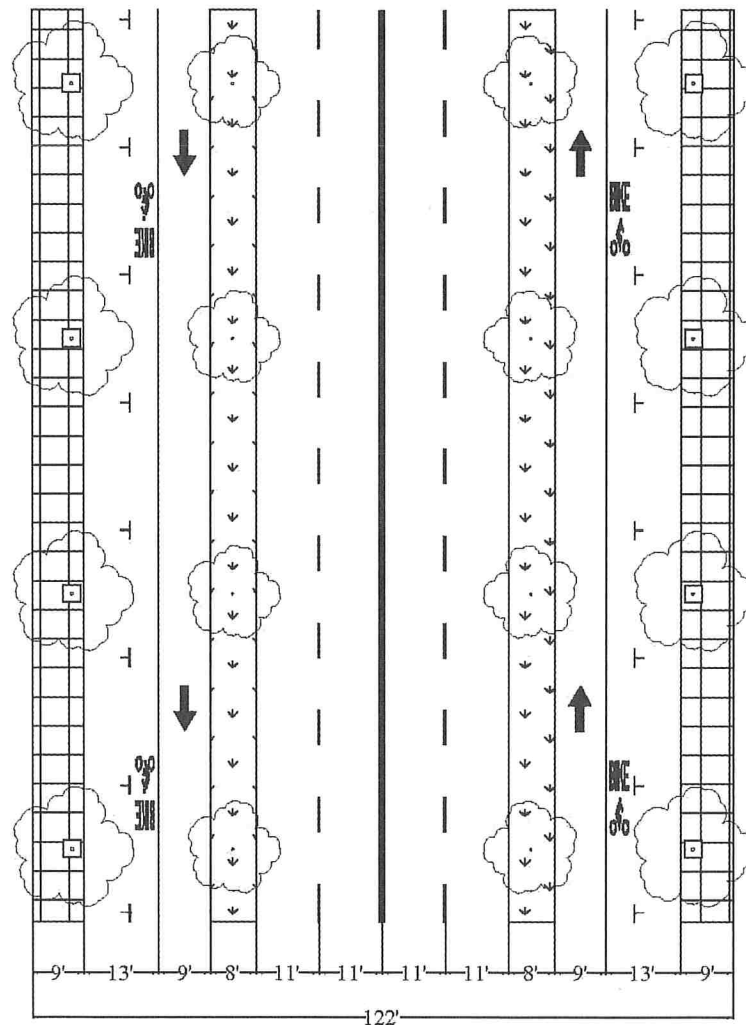
+ Fair

- Poor

-- Fails to meet/achieve objectives

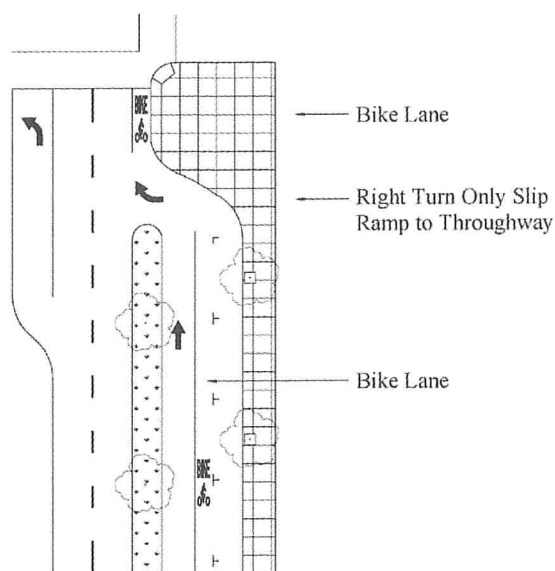
Source: ITE (2010a)

Exhibit 6-17. Schematic plan view of Alternative 2.



Source: ITE (2010a)

Exhibit 6-18. Alternative intersection design for Alternative 2.



Source: ITE (2010a)

6.4.8 Solution Design Features

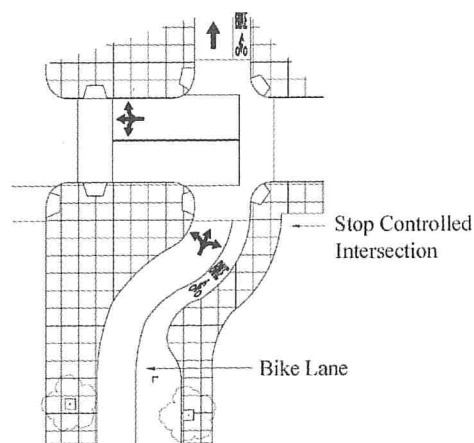
Traveled Way:

- Target speed: 35 mph;
- Four, 11-ft. travel lanes in central roadway;
- Parallel, 18-ft.-wide local access lanes separated by 8-ft.-wide landscaped medians;
- Local access roads provide shared vehicle/bicycle lane and 9-ft. travel lane; and
- Left-turn lanes on central roadway at intersections.

Streetside:

- 12-ft. sidewalks;
- Pedestrian-scaled lighting; and
- Street trees in tree wells.

Exhibit 6-19. Alternative intersection design for Alternative 2.



Source: ITE (2010a)

Intersections:

- Special design treatment required to accommodate multiple movements between central roadway and local access lanes; and
- Intersections widened to accommodate left-turn lane within the central roadway.

Parallel Thoroughfares (as needed):

- Directional signing;
- Operational adjustments or improvements; and
- Physical improvements.

6.5 Design Case Study D: 27th Avenue

The design alternatives case study for 27th Avenue is adapted from *NCHRP Report 785: Performance-Based Analysis of Geometric Design of Highways and Streets* (Ray et al. 2014). The purpose of this project is to design a new urban collector to provide additional connectivity in an industrial area and at the same time better balance modes using the roadway.

This case study illustrates how the performance-based analysis suggested by *NCHRP Report 785* can be incorporated into the design concept development process. It also demonstrates that evaluating and interpreting alternatives across multiple modes using a variety of performance measures can be a complicated exercise. For a more detailed version of this case study that includes the report author's notes, see *NCHRP Report 785*.

This project example considers alternative alignments and cross sections for a new urban collector roadway, 27th Avenue, which is being designed to provide additional connectivity within and access to an industrial area. The overarching intended project outcome is to entice and encourage new employers to the newly zoned industrial area. The city, within which the industrial area is located, would like to increase its industrial employment base.

The new urban collector would connect to the broader roadway network by way of existing US-33. The learning objectives for this project example are as follows:

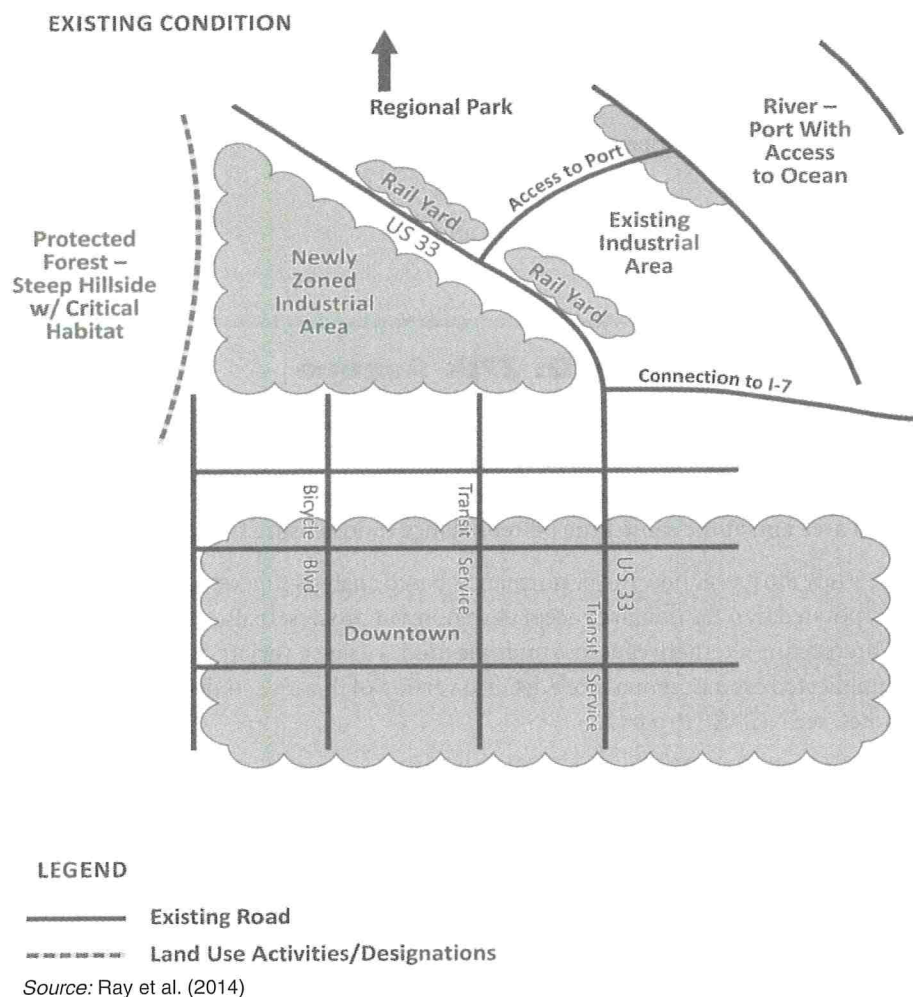
- Illustrate how to consider the broader context before beginning the details of design;
- Demonstrate how the needs of different modes can be balanced; and
- Apply the performance-based analysis process within an EA.

6.5.1 Project Initiation

Project Context

The city is trying to increase the number of industrial employment opportunities to create a more well-rounded local economy. The city council approved expanding the industrial zone adjacent to the existing heart of the city's industrial land uses. To draw in larger industrial-type employers and supporting services, the city is going to construct some of the necessary street infrastructure to make the new area viable for employers. The area is bounded by a steep hillside to the west, the downtown core to the south, and existing industrial uses to the north and east. An existing highway, US-33, runs along the newly zoned area's northeasterly border. Exhibit 6-20 illustrates the location of the expanded industrial zone.

Despite the proximity to rail, other industrial uses, and US-33 (a regional highway), there are some inhibitors for industrial employers. There is not sufficient connectivity within the newly zoned area to facilitate its use without heavy reliance on US-33. US-33 has relatively stringent access spacing standards, making it difficult to obtain access permits from the state DOT. Also, there are limited access points to the area and those that do exist are not consistently conducive

Exhibit 6-20. Existing conditions of new industrial area.

to heavy-vehicle traffic. US-33 serves the existing industrial uses in the area while being a critical connection between the downtown and a regional park located to the north. As a result, US-33 is heavily traveled by recreational bicyclists traveling between downtown and the regional park. This high demand occurs despite the lack of bicycle lanes on US-33 and the variation in the paved shoulder width from 2 to 4 ft. along the corridor.

6.5.2 Intended Project Outcomes

In this project example, the project purpose is to make improvements to the roadway network to encourage and entice employers to the existing industrial area. There are no direct geometric performance measures for evaluating how well a project alternative will encourage or entice employers to the industrial area. However, there are indirect geometric performance measures contributing to characteristics that would support encouraging employers within an industrial area (e.g., quality of service for large vehicles, access to regional highways or freeways).

City planners would like to address some of the inhibitors for industrial employers, while also addressing some of the issues related to mixed bicycle and heavy-vehicle traffic on US-33 within an area that does not have sufficient space for both modes. The city has decided to focus their investment on improving connectivity within the newly zoned area. In doing so, it hopes

to address some of the deterrents for employers and explore ways to improve bicycle accommodations from the downtown area to the regional park. The city's basic approach for achieving this goal is to plan, design, and construct a new urban collector, 27th Avenue, within the newly zoned industrial area.

The city plans to seek federal funding for part of the 27th Avenue project. Enough work has been done to know the project does not qualify for a categorical exclusion, and so the city needs to perform an EA to determine if the project could result in significant environmental impacts.

The project did not qualify for a categorical exclusion due to its proximity to the hillside (previously shown in Exhibit 6-20), which is a federally listed critical habitat. Considering the new 27th Avenue, the city will need to avoid, and demonstrate there is no, significant impact to the hillside from the 27th Avenue construction. If it is unable to demonstrate no significant impact, the city will need to produce an Environmental Impact Statement (EIS). The city would prefer to avoid significant environmental impact and, therefore, plans to adapt the 27th Avenue project design accordingly.

With respect to funding, a LID has also been formed to generate funds for ongoing maintenance and improvements within the newly zoned industrial area. The city will operate and maintain the roadway when it is constructed.

The primary audience to be served by this project is heavy-vehicle operators who will need to be able to easily access and circulate within the industrial area. The city knows this is a critical factor industrial businesses consider in selecting their location. The secondary audience of users who also need to be considered in developing 27th Avenue are bicyclists and motorists traveling between the regional park and downtown districts. The other participating stakeholders are the business owners in the area participating in the LID that will help with funding 27th Avenue.

From the city's perspective, the overarching intended outcome of the project is to entice industrial employers to the newly zoned industrial area. The city wishes to generate employment opportunities for a currently under-employed segment of the city's population. No clear direct performance measures connect design decisions to generation of additional industrial-based jobs within an area. Surrogate transportation performance categories and associated measures reflecting the type of roadway system industrial-based businesses value are identified as accessibility, quality of service, and safety. The performance measure to be used for access is the ease with which heavy vehicles will be able to navigate the industrial area and the quality of access to US-33 and the downtown. The performance measure selected to measure quality of service is MMLOS performance for bicyclists (to access the regional park) and transit riders (to serve employees accessing jobs within the industrial area). The expected frequency and severity of crashes will be used to measure safety.

6.5.3 Concept Development

Geometric Influences

The *NCHRP Report 785* project team decided to focus the initial alternative development and analysis on two elements: (1) obtaining a finding of no significant environmental impact and (2) creating design attributes and parameters supporting the transportation performance measures previously identified.

Roadway alignment is the primary factor influencing whether the 27th Avenue project can avoid a significant environmental impact. The critical habitat is part of the hillside and the base of the hillside along the western border of the newly zoned industrial area. Therefore, horizontal alignment of 27th Avenue is one area of focus and consideration with respect to geometric design decisions.

In addition to the roadway alignment, the project team focused on defining a set of cross-section design parameters that can be used to develop 27th Avenue. The cross sections must balance some of the performance trade-offs between access for heavy vehicles, quality of service for bicyclists and transit riders, and safety across modes. The project team selected the following design parameters to explore because of their direct relationship to the previously mentioned performance measures:

- Intersection geometry as it relates to being able to accommodate large vehicles (e.g., radius of curb returns);
- Lane width;
- Bicycle facility presence and type (e.g., bicycle lanes);
- Ability to accommodate transit; and
- Sidewalk presence and width for pedestrians and transit riders.

6.5.4 Potential Solutions

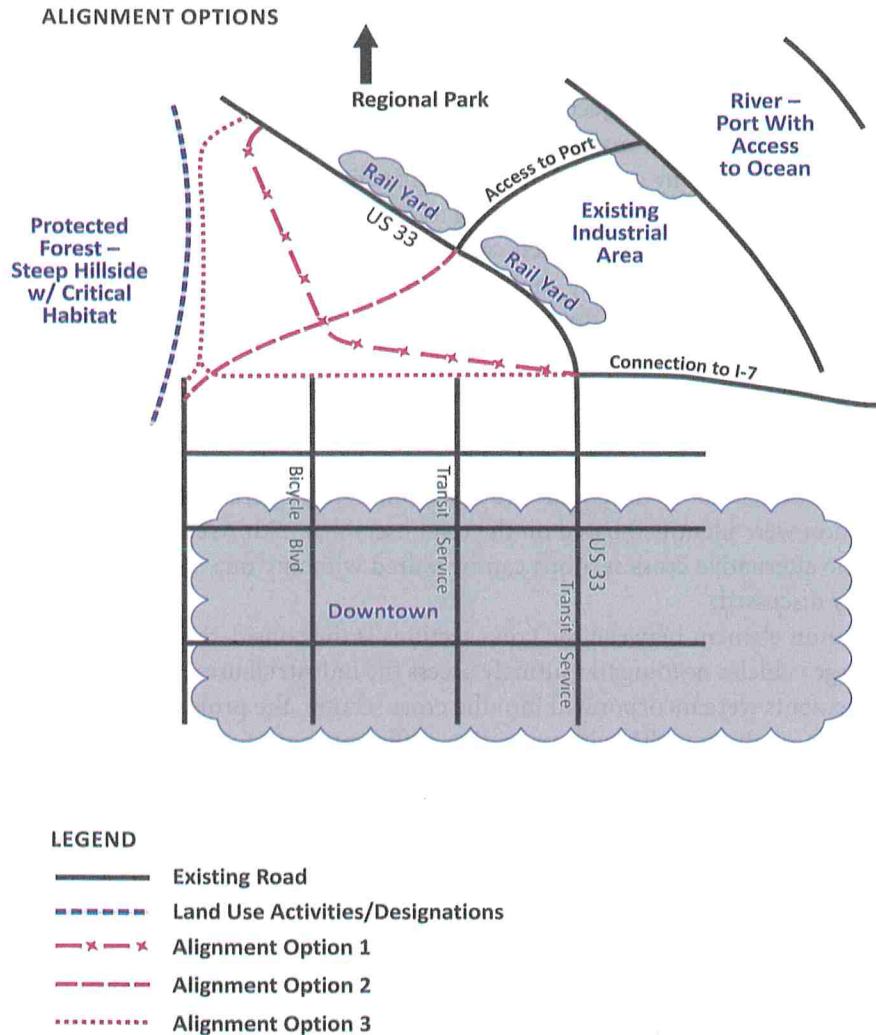
The project team's initial effort focused on defining the alignment for 27th Avenue. Three alignment options were developed and assessed based on their ability to avoid a significant environmental impact, provide access to US-33 and downtown, and facilitate circulation within the industrial-zoned area. In addition, the alignments ideally should not preclude reasonably sized parcels for large and smaller supporting employers. A brief description of each of the alignment options follows:

- Alignment 1 (US-33 and Interstate Access): Provides connection to US-33 and to I-7; divides the newly zoned area into four quadrants;
- Alignment 2 (Rail Yard and Port Access): Provides a direct connection to US-33, rail yard and port; divides the newly zoned area into two large parcels; and
- Alignment 3 (US-33, Interstate, and Downtown Access): Provides a connection to US-33, I-7, and three minor arterials in the northern downtown core; maintains the most contiguous amount of industrial land.

Exhibit 6-21 illustrates the alignment options. Each of the alignment options can be paired with a set of design parameters helping to define the 27th Avenue cross section.

The project team developed three sets of alternative design parameters considering the different road users to be served by 27th Avenue:

- Alternative 1 (Freight Oriented): A set of design parameters focused on characteristics facilitating the movement of large vehicles;
- Alternative 2 (Freight with Bicycle Accommodations): A set of design parameters incorporating characteristics for large vehicles and bicyclists; and
- Alternative 3 (Complete Street): A set of design parameters considering characteristics of large vehicles, bicyclists, and transit riders.
- **Resources used to develop solutions.** The *NCHRP Report 785* project team used *A Policy on Geometric Design of Highways and Streets* (AASHTO 2011a), the city's roadway design standards, the state's highway design manual and the *Urban Street Design Guide* (NACTO 2013) as references and guidance documents to develop specific alternatives for evaluation.
- **Solution development.** In this project, the project team was challenged to consider a range of options for an alignment as well as cross-section characteristics to try to achieve the varied performance measures previously discussed. To keep the solution development within a reasonable scope of effort, the project team focused the alignment options on avoiding significant environmental impacts, providing access to the broader transportation network, and enabling onsite circulation. The options identified for the roadway cross-section design

Exhibit 6-21. Alignment options for 27th Avenue.

Source: Ray et al. (2014)

parameters are focused on elements that provide sufficient space for heavy vehicles (as a form of accessibility), quality of service for bicyclists and transit riders, and safety. In developing the alignment options, some consideration also was given to how to augment the options to better serve (1) bicyclists currently using US-33 to access the regional park and (2) safety with respect to speed management.

- **Alignment options for 27th Avenue.** Alignment options for 27th Avenue were developed considering the connections to regional transportation facilities and the need to avoid a significant environmental impact. The potential connections to regional transportation facilities include the following:
 - US-33: A highway serving as a key transportation freight corridor reaching from coastal communities west of the industrial area to urban, suburban and rural mountain communities east of the industrial area;
 - I-7: An Interstate freeway passing north-south through the state, connecting the majority of the major coastal cities and ports;
 - Rail yard: The rail yard is served by two major freight rail lines traversing east-west across the state, ultimately connecting to a major interstate rail hub;

- Port (river): Provides access to large merchant and freight-carrying ships with access to the ocean and, therefore, access to a wide range of global ports; and
- Downtown: Connection to areas where employees will be traveling to and from their places of residence, and connection to existing transit service and bicycle boulevards.

The *NCHRP Report 785* project team explored different options and degrees of direct connections to these regional transportation facilities. There are advantages and disadvantages to directly connecting to any one of these regional facilities. The direct access can be attractive to industrial employers; however, depending on the existing operations of that facility, it may result in operational delays or limited capacities by adding industrial traffic directly to an already well-used facility. Directly connecting to the downtown also presents potential considerations with respect to cut-through traffic and the general advantages and disadvantages of expanding the downtown street grid.

One key advantage the city wanted to capture in one of the options was the ability to provide an alternate route and better quality route for bicyclists traveling to the regional park so bicyclists would not be forced to use US-33.

- **Design parameters for 27th Avenue cross section.** Design parameters for the 27th Avenue cross section were identified based on the road users that 27th Avenue is intended to serve. Any of the alternative cross sections can be paired with any one of the alignment options previously discussed.

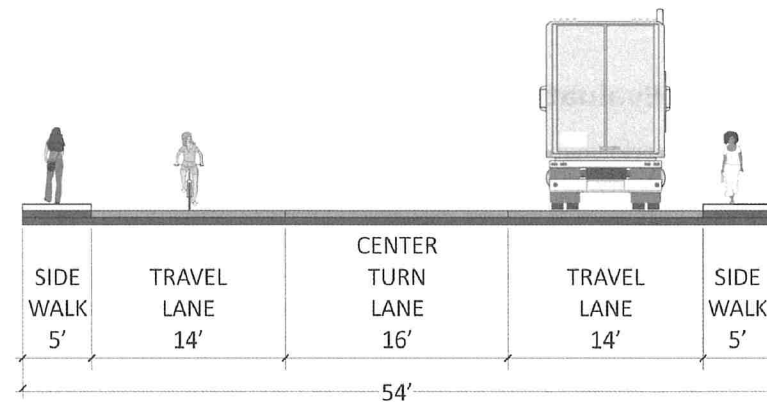
A common element between the cross sections is the consideration given to accommodating large vehicles needing to routinely access the industrial uses. As additional road user design elements were incorporated into the cross section, the project team tried to balance the ultimate roadway width with providing sufficient space for different road users. This was an ongoing trade-off in developing and evaluating the different cross sections. The city would like to keep the total cross-section width as narrow as possible while still meeting road users' needs. A narrower cross-section footprint will allow more space for the industrial uses and employers that the city would like to attract to the area. The clear trade-off in keeping the roadway cross-section footprint narrow is having less space to serve the large vehicles, bicyclists, and transit riders who are anticipated to use 27th Avenue.

The city made one overarching design decision applied to each alternative cross section. The city decided 27th Avenue will be an undivided roadway facility; therefore, none of the alternatives could include a center median. The primary reason for this decision was to keep the roadway cross section open and free of physical obstacles, providing more space and options for drivers of heavy vehicles to navigate the industrial area.

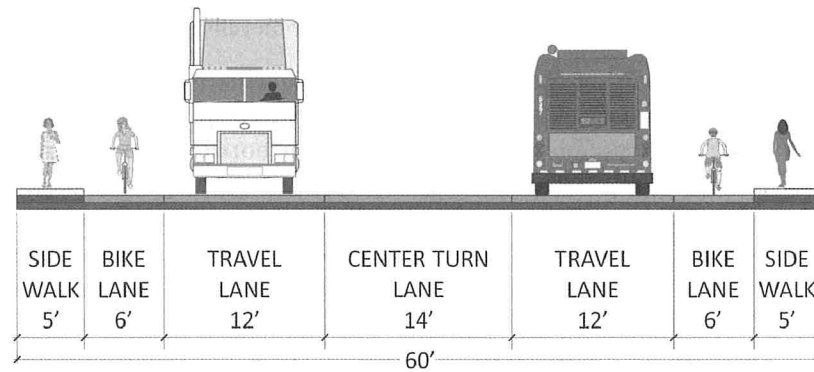
6.5.5 Primary Alternatives for Evaluation

Using the resources and considerations briefly described previously, the project team arrived at the alignment options shown in Exhibit 6-21 and the following alternative cross sections for evaluation:

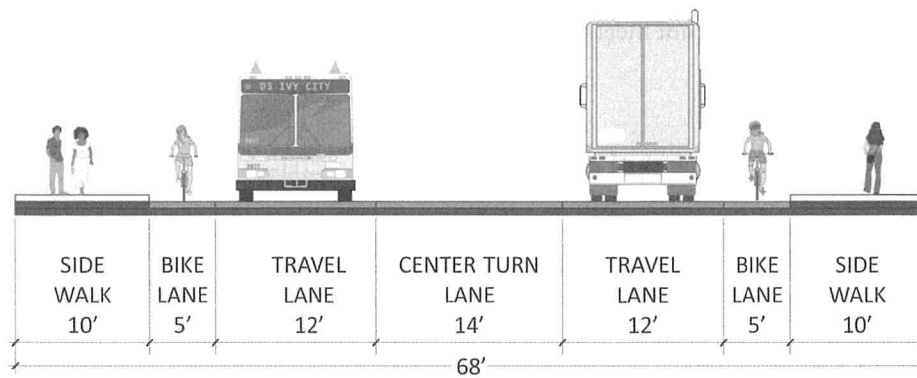
- Alternative 1 (Freight Oriented): Two-lane roadway with 14-ft.-wide travel lanes and a 16-ft.-wide, two-way center left-turn lane (total three-lane cross section); the cross section includes curb-tight 5-ft.-wide sidewalks on both sides of the street (see Exhibit 6-22).
- Alternative 2 (Freight with Bicycle Accommodations): Two-lane roadway with 12-ft.-wide travel lanes and a 14-ft.-wide two-way center left-turn lane (total three-lane cross section); the cross section includes 6-ft.-wide bicycle lanes and curb-tight 5-ft.-wide sidewalks on both sides of the street (see Exhibit 6-23); and
- Alternative 3 (Complete Street): Two-lane roadway with 12-ft.-wide travel lanes and a 14-ft.-wide two-way center left-turn lane (total three-lane cross section); the cross section includes 5-ft.-wide bicycle lanes and 10-ft.-wide pedestrian space on both sides of the street (see Exhibit 6-24).

Exhibit 6-22. Cross section of Alternative 1.

Source: Ray et al. (2014)

Exhibit 6-23. Cross section of Alternative 2.

Source: Ray et al. (2014)

Exhibit 6-24. Cross section of Alternative 3.

Source: Ray et al. (2014)

The exhibits show there are a few common elements across the alternative cross sections:

- A two-way center turn lane to facilitate access to future industrial uses fronting 27th Avenue;
- Sidewalks to separate pedestrian activity and vehicle movement; and
- One through travel lane in each direction, which was deemed sufficient given that 27th Avenue will primarily facilitate internal circulation.

6.5.6 Evaluation and Selection

The performance evaluation for the alternative alignment options was based on each alignment's ability to:

- Avoid significant environmental impacts;
- Facilitate circulation and connections to regional transportation facilities;
- Maintain contiguous parcels of land for industrial uses; and
- Create an improved alternative route to the regional park.

The performance evaluation for the alternative cross sections focused on the following performance categories and associated measures:

- Safety, as defined by crash frequency,
- Accessibility, as defined by connectivity within the industrial area, connection to the regional park, connection to regional highways and ability to accommodate large vehicles; and
- QOS, as defined by accommodations for bicyclists and transit riders.

The alignment options were evaluated qualitatively across the previously listed attributes. The project team used geographic information system (GIS) software, aerial imagery, initial surveys and preliminary engineering of the horizontal alignments to assess how each option performed relative to the attributes. The GIS mapping enabled the team to identify and determine the locations of environmentally sensitive areas along and at the base of the hillside that needed to be avoided. The identification of sensitive areas considered the physical impact of the roadway and industrial development as well as where and how stormwater runoff from 27th Avenue and the newly zoned industrial area will be managed. The aerial imagery, initial survey of the industrial area and preliminary engineering of the horizontal alignments, paired with the GIS information, enabled the project team to complete informed assessments of the alignment options.

Exhibit 6-25 summarizes the qualitative assessment results for the alignment options. Each alignment option was rated for the performance criteria using a scale of 0 to 3. A 0 indicates the option did not meet the criteria and a 3 indicates the option fulfills the criteria.

Exhibit 6-25. Assessment of alignment options.

Alignment Options	Avoid Env. Significant Impact	Connection to Regional Facilities	Circulation within Area	Contiguous Parcels of Land	Improved Alternate Route to Regional Park	Total Score
1: US-33 and I-7 Access	3	2	2	1	1	9
2: Rail Yard and Port Access	3	2	2	2	0	9
3: US-33, I-7 and Downtown Access	3	3	3	3	3	15

Source: Ray et al. (2014)

Alignment 3 scored the highest based on the criteria because this alignment:

- Avoids significant environmental impacts and establishes a western border for the newly zoned area. This means incoming industrial uses and employers will only be able to develop east of 27th Avenue. This guarantees no negative impacts to the hillside and will save interested employers from having to evaluate and/or seek environmental clearance to move into the newly zoned area.
- Provides a connection to US-33 in two locations. This alignment also provides a direct connection to I-7 on- and off-ramps. Finally, it connects with three minor arterials in the northern downtown core. One arterial is an existing bicycle boulevard and one has an existing transit line.
- Provides circulation within the newly zoned area along the western and southern border.
- Maintains the largest amount of contiguous parcels of land, providing potential employers with flexibility in their site development.
- Provides a more direct connection and an alternate parallel route to US-33 for bicyclists to reach the regional park.

Alignments 1 and 2 performed well for some of the evaluation criteria but were weakest in maintaining contiguous parcels of land for development and providing an alternate route to the regional park.

For the alternative cross sections, the performance measures associated with the identified performance categories were estimated using the following resources:

- **Safety.** Chapter 12 of the AASHTO HSM (AASHTO 2010) was used to estimate the expected safety performance;
- **Accessibility.** Access was evaluated qualitatively based on the physical space allocated to heavy vehicles; access with respect to connectivity within the area and to regional transportation facilities was captured in the assessment of the alignment options;
- **QOS.** The HCM 2010 MMLOS methodology (TRB 2010) was used to evaluate the quality of service (i.e., quality of the travel experience perceived by the road user) anticipated for bicyclists and transit riders.

Exhibit 6-26 summarizes the evaluation results for each alternative. The qualitative scale used to evaluate access for heavy vehicles was a rating of poor, fair or good based on the degree to which the cross section is anticipated to accommodate heavy vehicles.

As shown in Exhibit 6-26, each cross section is estimated to have the same number of crashes per year even though the alternatives involve differences in lane width, bicycle lane presence and width, and sidewalk width. The reason the expected crashes per year do not change across the alternatives is because the methodology in Chapter 12 of the HSM applicable to urban and suburban facilities is not able to quantify the safety effects of changes in lane width, presence or width of bicycle lanes, or the presence or width of sidewalks (AASHTO 2010). This is, in part,

Exhibit 6-26. Evaluation of alternative cross sections.

Alternative Cross Sections	Safety (crashes/year)	QOS		Access for Heavy Vehicles
		Bicycle MMLOS	Transit Riders MMLOS	
1: Freight Oriented	2.3	E	E	Good
2: Freight with Bicycle	2.3	C	C	Fair
3: Complete Street	2.3	C	B	Fair

Source: Ray et al. (2014)

why the project team also evaluated the quality of service for bicyclists and transit riders using the HCM 2010 MMLOS methodology. That methodology is sensitive to the presence and width of bicycle lanes and sidewalks. Looking across the performance results of the alternative cross sections, Alternatives 2 and 3 seem to offer the more balanced options for multiple road users, whereas Alternative 1 clearly favors heavy-vehicle traffic.

The project team developed cost estimates for each alignment option and alternative cross section to evaluate the financial feasibility of each combination for the 27th Avenue project. The cost estimates for the alignment took into consideration the length of the proposed alignment and the cost per linear foot of the alternative cross sections. The costs include considerations such as stormwater management, full-depth pavement given the anticipated high volume of heavy vehicles, signing, pavement markings, lighting and a contingency cost for unforeseen expenses or fluctuations in material costs. Exhibit 6-27 summarizes the cost estimates.

The significant drivers of cost are the length of the alignment and width of the cross section. Alignment 3 is the longest alignment option; the cost estimates for the different cross sections for that option are greater than for alignments 1 and 2. Similarly, Alternative 3 is the widest cross section; therefore, across each of the alignment options, Alternative 3 has the highest associated cost.

The project team did not estimate a benefit/cost ratio or calculate a cost-effectiveness factor for the different alignment options and alternative cross sections. To be able to calculate a benefit/cost ratio or cost-effectiveness factor, simplifying assumptions would be needed to convert the assessment of alignment options into monetary benefits. Additional assumptions would be needed to quantify the degree of access provided to heavy vehicles for each alternative. The project team determined such assumptions would be vulnerable to subjectivity and might convolute the assessments previously performed in the project. Therefore, the city used the cost estimates in combination with the performance evaluations to build internal consensus and solicit input from external stakeholders to work toward a selected alternative.

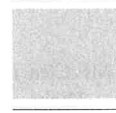
6.5.7 Selected Alternative

The city and project stakeholders selected Alignment 3 paired with cross-section Alternative 2. Alignment 3 performed the best in the performance evaluation and especially well with respect to providing access to regional facilities and an alternate route for bicyclists to access the regional park. Alternative 2 was selected because it provided the most balanced means for serving heavy vehicles and bicyclists while managing cost and overall footprint of the roadway. Transit riders and pedestrians can also be served with Alternative 2 and, therefore, the city felt it was the most balanced overall solution.

Exhibit 6-27. Cost estimates for 27th Avenue.

Alignment Option	Alternative Cross Section	Estimated Cost
1: US-33 and I-7 Access	1: Freight Oriented	\$1.1 million
	2: Freight with Bicycle Accommodations	\$1.3 million
	3: Complete Street	\$1.5 million
2: Rail Yard and Port Access	1: Freight Oriented	\$700,000
	2: Freight with Bicycle Accommodations	\$850,000
	3: Complete Street	\$1.0 million
3: US-33, I-7, and Downtown Access	1: Freight Oriented	\$1.3 million
	2: Freight with Bicycle Accommodations	\$1.4 million
	3: Complete Street	\$1.6 million

Source: Ray et al. (2014)



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Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI-NA	Airports Council International-North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TDC	Transit Development Corporation
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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